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BLAST LOADING OF CLOSURES FOR USE ON SHELTERS-II

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results are presented for the blast loading of expedient closures intended for use in the key worker shelter pressure range. Failure levels were determined for long duration blast loads from the BRL 2.44 m simulator. Loading data and high speed photographs describe the failure modes.

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SUMMARY

I. INTRODUCTION

The work reported here is a part of a research project, funded by the Federal Emergency Management Agency (FEMA), Interagency Agreement No. EMW-E-1025, to upgrade existing shelters in both the key worker and host area. The objective of this study is to determine suitable shelter entry structures and non-accessway closures. Working curves for the selection of expedient closure materials versus opening size were checked for the key worker pressure level.

II. EXPERIMENT

Closures were constructed from aluminum skins/I-beams and plywood skin/thick beams. Opening widths covered were 76.2 cm (30 in.) and 121.9 cm (48 in.). Blast loading was applied to the closures by the BRL 2.44 m shock tube. All closures were loosely supported at the end of the shock tube. Pressure time histories of the input loads are given along with high speed photographs of the closures' failure modes. Average debris velocities were calculated for the closure fragments during breakout.

III. RESULTS AND CONCLUSIONS

Loading-time records for the closures are shown in the body of the report. The materials versus opening curve for expedient closure materials has been verified for the key worker blast level. It should be noted that only the best grade wood will serve as closures at this level. Due to the briefness of this effort, no poles or posts were tested. Only planks and beams were used to construct the wood closures. The aluminum welded skin/I-beam closures were found to be unsatisfactory due to general failure of the plug welds. Other fasteners would have probably proved more effective.

It is recommended that the material versus opening curves now being used at 275.8 kPa (40 psi) not be used over that level. Revised handbook curves should be published if it is desired to exceed this pressure level.

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I. INTRODUCTION

This report describes a study conducted at the Ballistic Research Laboratory (BRL) which was funded by the Federal Emergency Management Agency (FEMA), Interagency Agreement No. EMW-E-1025, Work Unit 1123C. The general objective of the work being reported was to test a variety of materials suitable for the upgrading of shelter entry structures and non-accessway closures. These are intended for use at the key worker level of blast pressure.

Previous work at BRL[1-4] sponsored by FEMA has verified design procedures[5] indicating that plywood and plywood stressed-skin panels are effective closures for small vent-type openings in the risk area (345 kPa, 50 psi) if there are suitable supporting fixtures. The present research was aimed at determining the material thickness required to close entry way-sized openings.

Material thickness curves were to be verified for inclusion into the revised Industrial Protection Manual.[6]

The types of closures prepared for testing were aluminum I-beams with aluminum skins, wood beams, and wood planks protected with sand bags.

II. TEST PROCEDURE

The test fixture, closures, and recording/data reduction instrumentation are briefly described in this section.

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[1] *G.A. Coulter, "Debris Hazard from Blast Loaded Plywood Sheet Closures," Memorandum Report ARBRL-MR-02917, Ballistic Research Laboratory, March 1979 (AD A071460).*

[2] *G.A. Coulter, "Blast Loading of Construction Materials and Closure Designs," Memorandum Report ARBRL-MR-02947, Ballistic Research Laboratory, August 1979 (AD A077116).*

[3] *G.A. Coulter, "Blast Loading of Wall Panels and Commercial Closures," Memorandum Report ARBRL-MR-03154, Ballistic Research Laboratory, February 1982 (AD B063574L).*

[4] *G.A. Coulter, "Blast Loading of Closures for Use on Shelters," Memorandum Report ARBRL-MR-03279, Ballistic Research laboratory, June 1983 (AD A130028).*

[5] *H.L. Murphy, "Upgrading Basements for Combined Nuclear Effects: Predesigned Expedient Options II," SRI Project 6876 Technical Report, July 1980.*

[6] *"Industrial Protection Manual, Booklet 10," SSI Report No. 8011, Scientific Service, Inc., June 1981 (AD A102631).*

A. Test Fixture

The test fixture used was the same as that used in References 3 and 4. It was attached to the end of the BRL 2.44 m shock tube[7] in the usual manner. A rectangular opening 1.219 x 1.676 m (4 x 5.5 ft) was used for all the tests except for the last one. The opening was changed to 0.762 m x 1.676 m (30 in. x 5.5 ft) for this shot.

All panels were loosely supported on the long vertical sides of the opening of the test fixture. Small corner tabs kept the closures from falling back into the shock tube. The vertical mounting position of the closures allowed reflected pressure to be applied by the blast wave. Figure 1 shows the test fixture used.

B. Closures

Sketches of the closures are shown in Figures 2-5.

The aluminum closure of Figure 2 consisted of six I-beams spanning the short dimension of the test fixture opening. The closure overhang was 7.62 cm (3 in.) on each of the two long bearing sides. The aluminum face sheets were plug welded to each I-beam with groups of eleven welds on each beam. The welds averaged about 1.27 cm (0.5 in.) in diameter.

Figure 3 shows a sketch of the wood beam closure. Two were made with pine beams and one from oak beams. The upstream plywood served as an air seal and was not intended to add any strength to the closure. Side support overhang was 15.24 cm (6 in.) on each of the long vertical bearing sides.

Figure 4-A shows the oak plank closure and Figure 4-B how it was mounted in the shock tube with sand bags.

For the smaller panel width the test fixture opening was modified to a width of 76.2 cm (30 in.) by adding vertical side supports before the last shot. Figure 5 shows the closure. All wood closures were banded as shown in the sketches to allow easier handling of the closures.

C. Instrumentation

The blast load applied to the closure was measured either on the end plate of the test fixture or 61 cm (24 in.) upstream when the sand bags were in place. See Figure 4-B above. The latter location used was just in front of the sand bags. The output from the quartz tranducer (PCB Model 113A24) was suitably amplified and recorded by the FM Honeywell 7600 tape recorder. Records were available for a quick-look from an on-site oscillograph to determine needed changes for the next test. See Figure 6 for a diagram of the data acquisition-reduction system used.

[7] *B.P. Bertrand, "BRL Dual Shock Tube Facility," Ballistic Research Laboratory Memorandum Report 2001, August 1969 (AD 693264).*

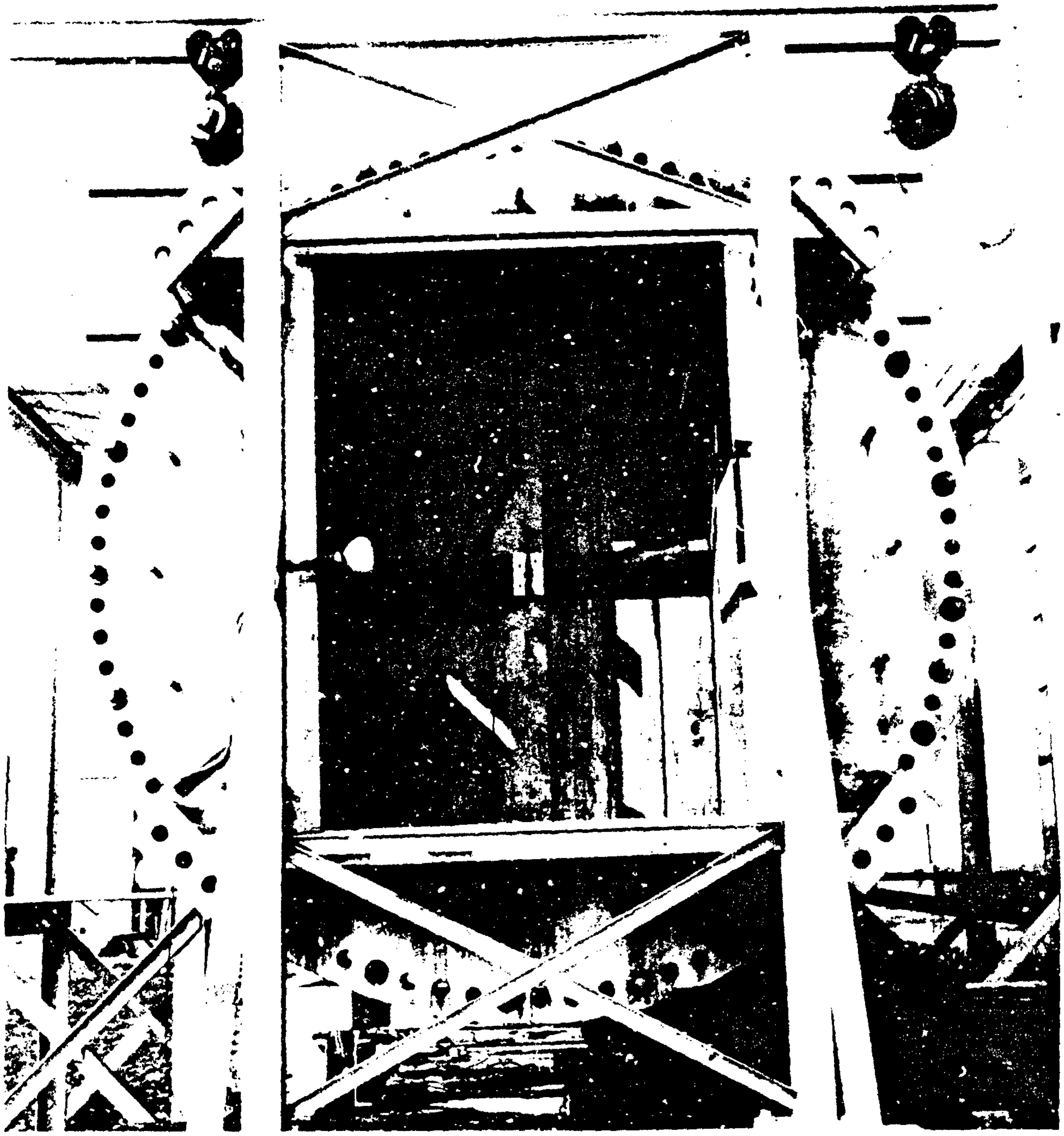


Figure 1. Test Fixture - 2.44 m Shock Tube.

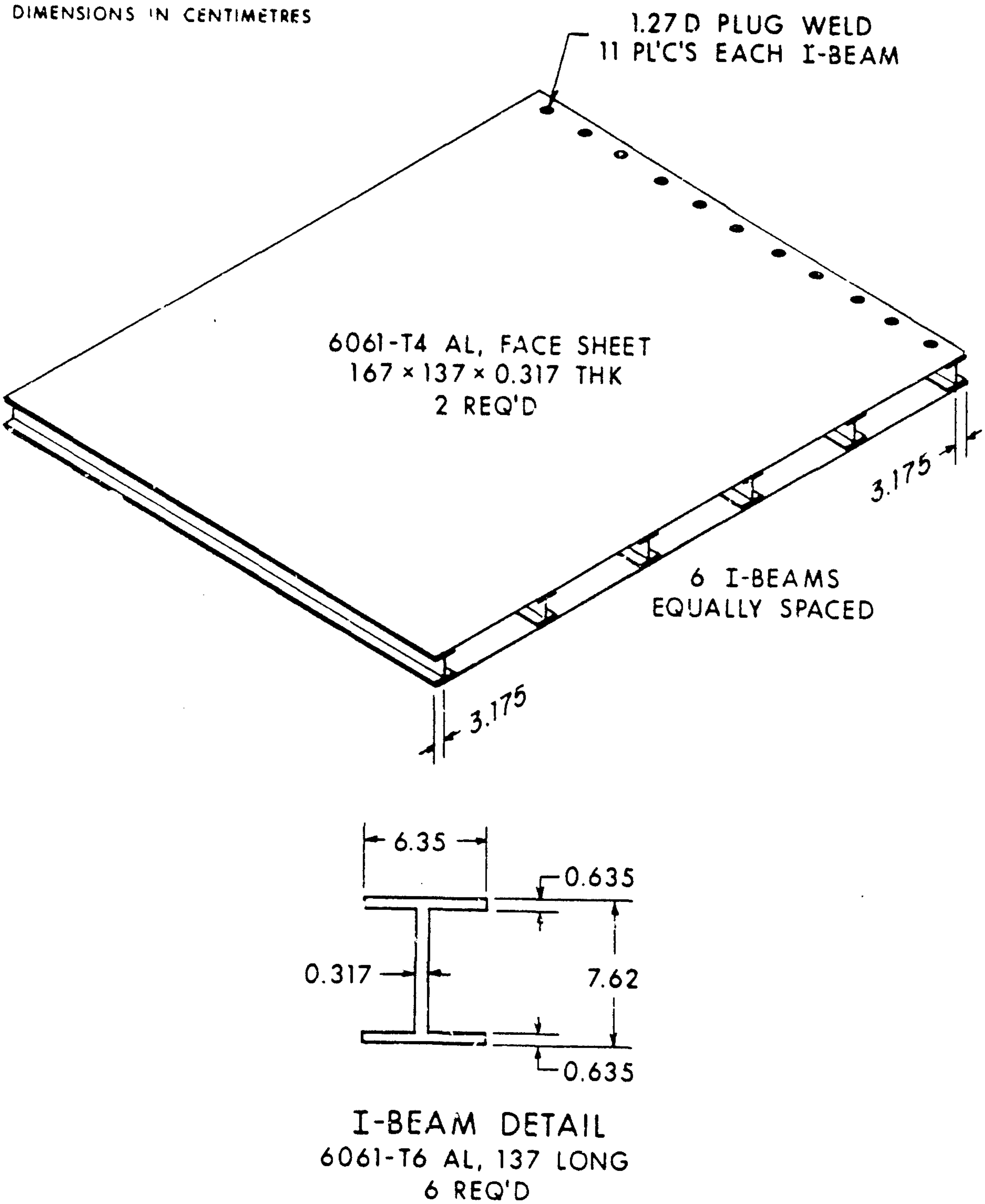


Figure 2. Aluminum Skin/I-Beam Closure.

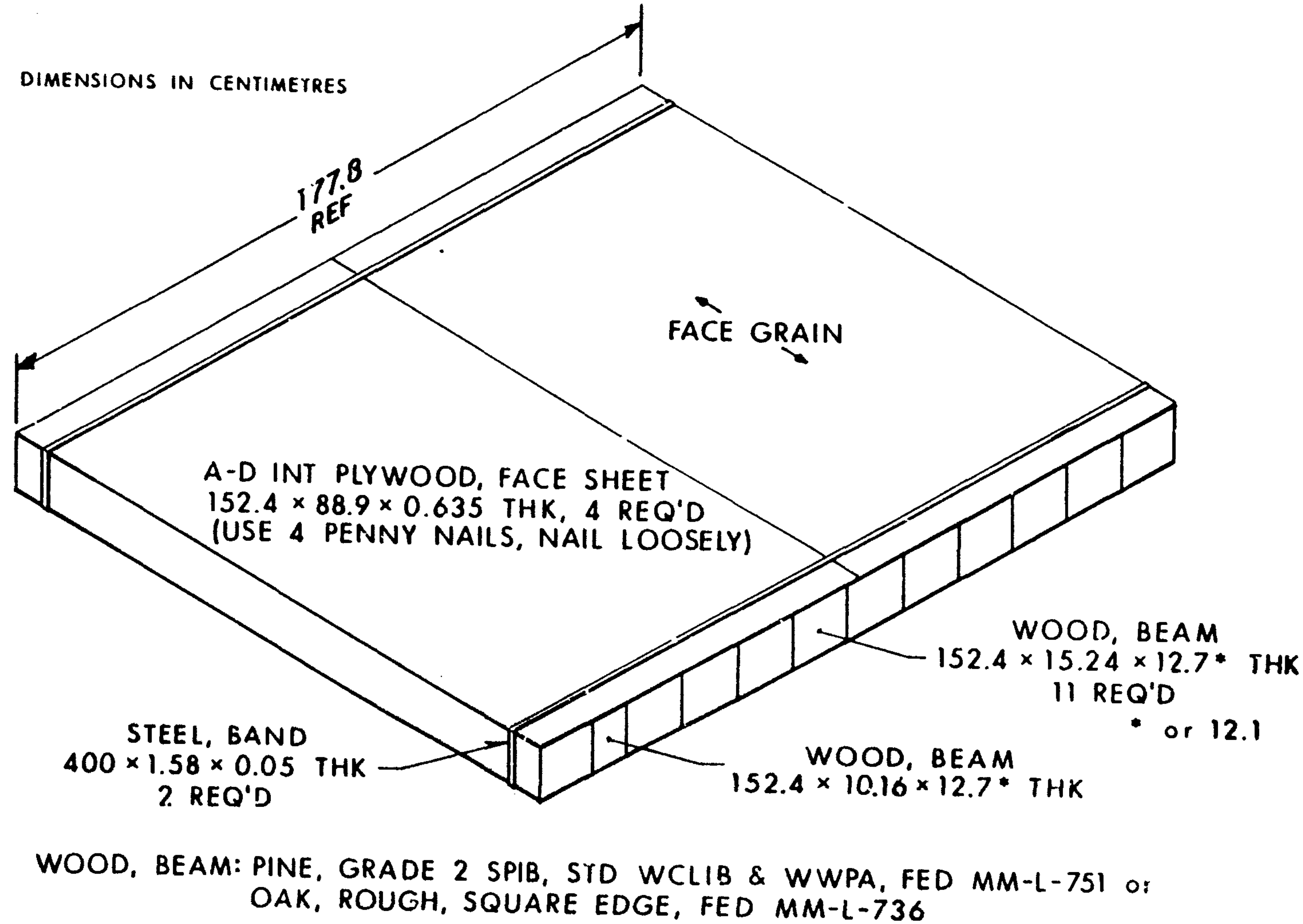
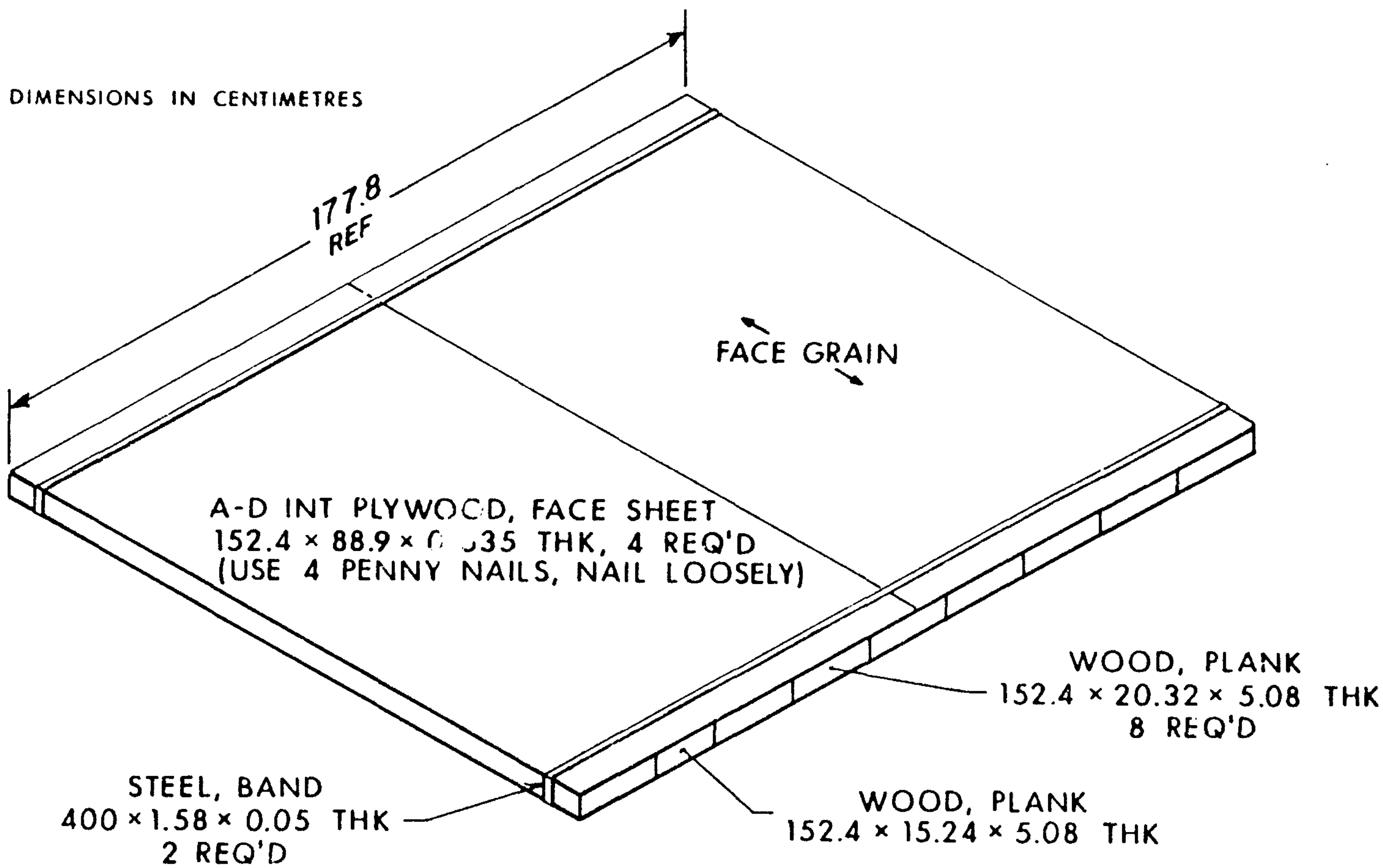
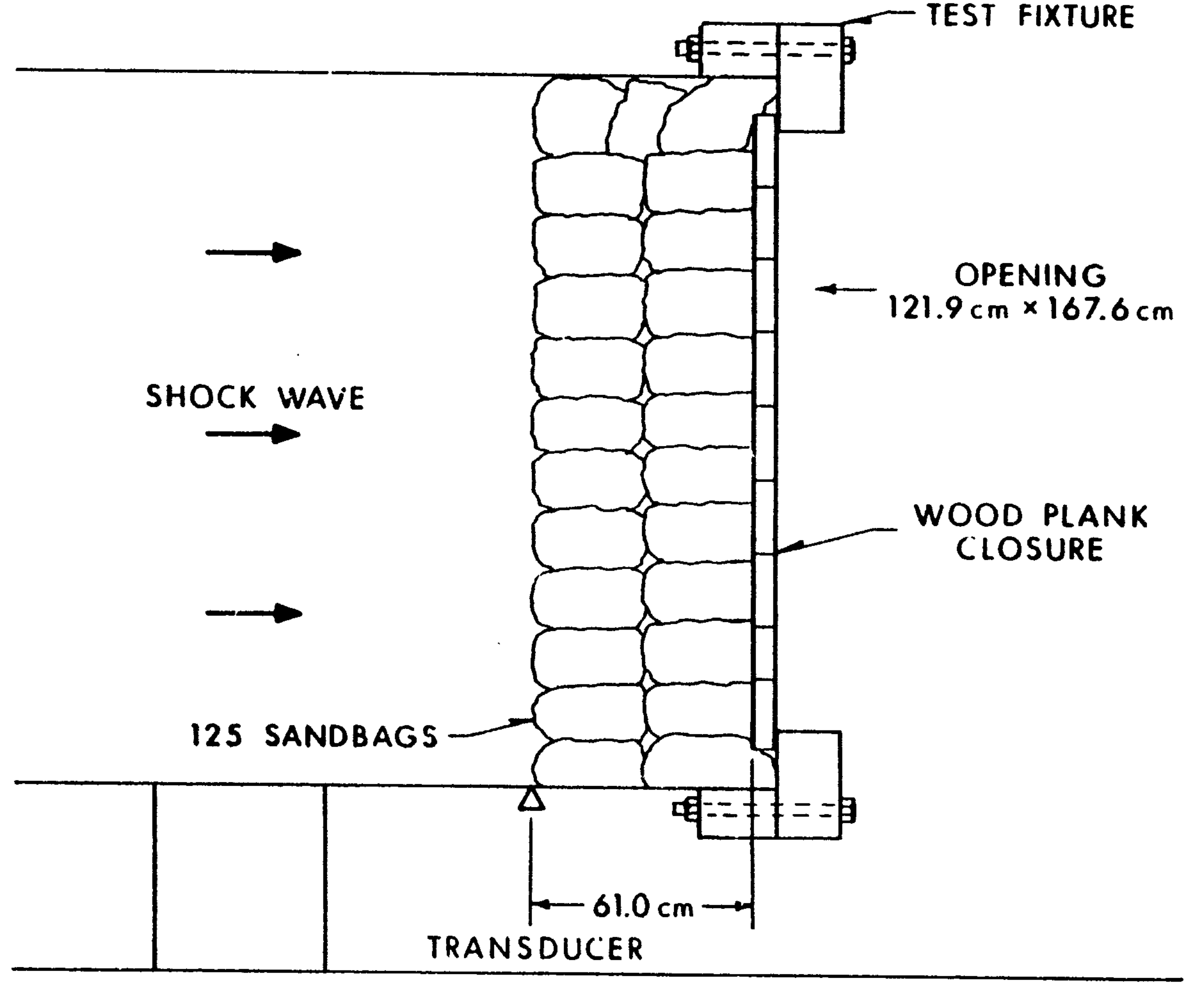


Figure 3. Wood Beam Closure.



A. Wood Plank Closure.

Figure 4. Wood Plank/Sand Bag Closure.



B. Wood Plank Closure in Shock Tube.

Figure 4 (Cont'd). Wood Plank/Sand Bag Closure.

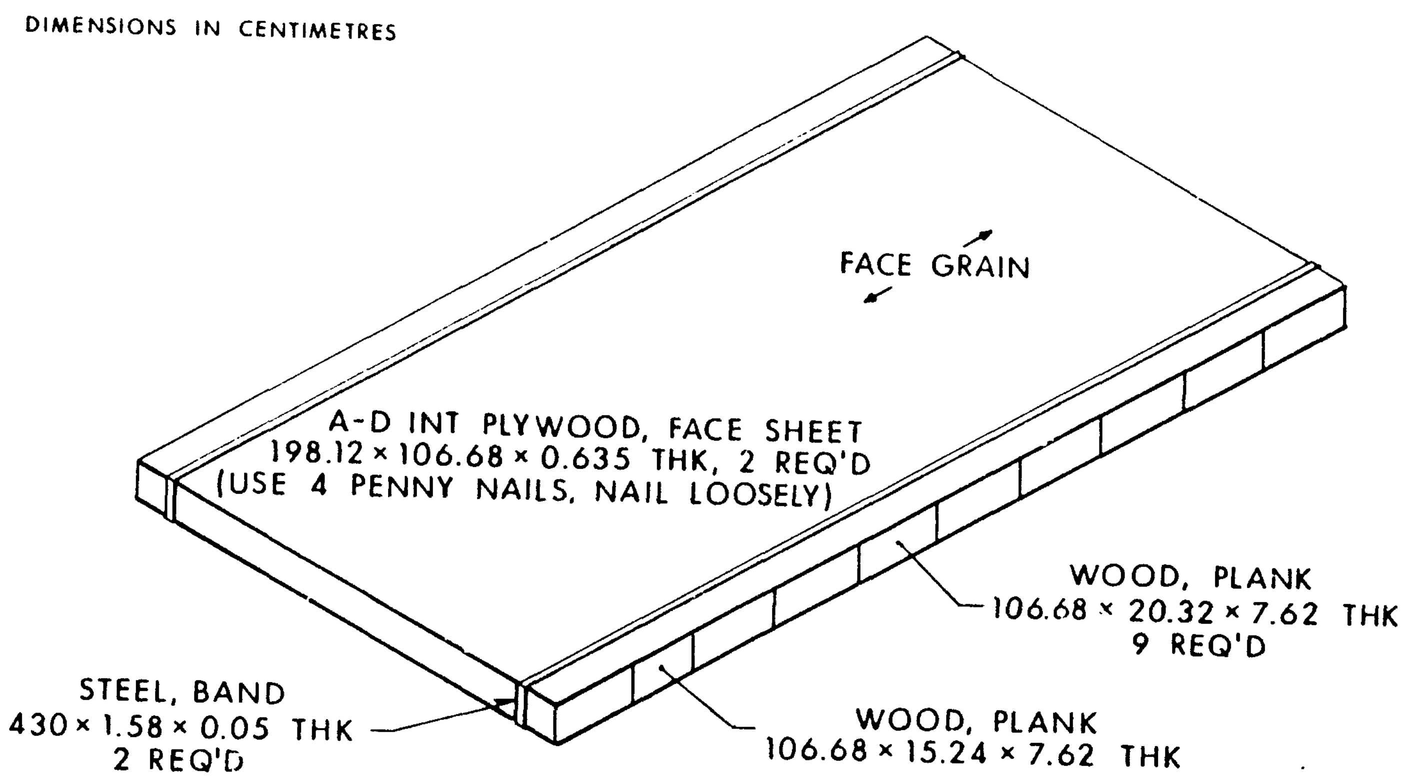


Figure 5. Wood Beam Closure - Small Opening.

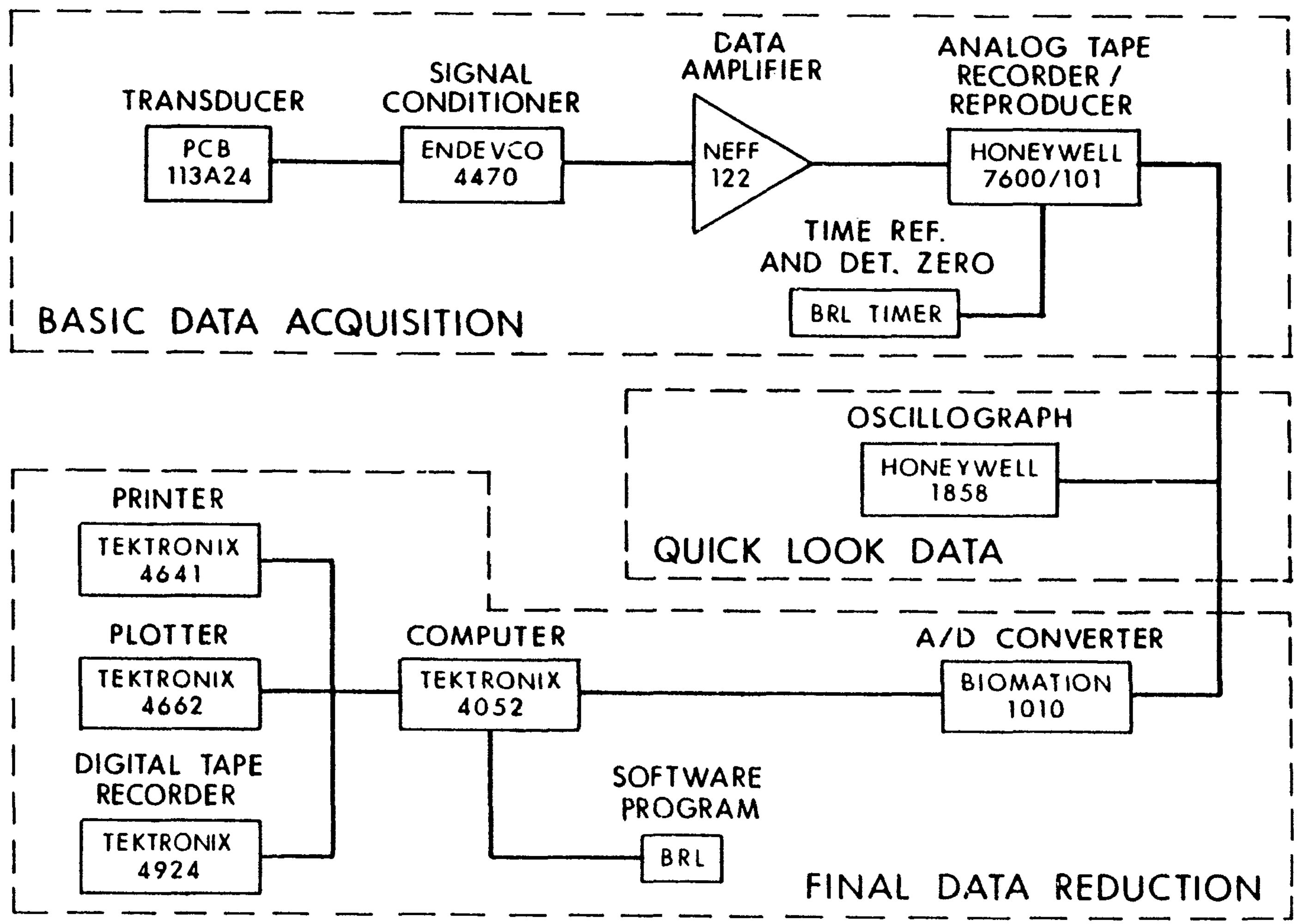


Figure 6. Schematic of Data Acquisition - Reduction System.

The mode of failure and debris pattern for the closures were recorded by means of a high speed camera (Red Lakes HYCAM) operating at 500 pictures per second (PPS). Debris average velocities were calculated from these photographs.

III. RESULTS

The results are given in the data table, as pressure-time loading records, and in high speed photographs.

A. Data Table

The test conditions for each type of closure are listed in Table 1. Ambient conditions, loading pressures, opening widths, and damage results are listed for each shot in the series.

Two general ranges of loading were applied to the closures. The first included 253 and 247 kPa (36.7 and 35.8 psi) applied to the aluminum panel closures. A level of loading at about 345 kPa (50 psi) was planned for all the wood beam closures. The variation was found to be between 342 and 351 kPa (49.6 and 50.9 psi) for the test series on the wood closures. Total failure occurred at these ranges except for the oak beam closure exposed in Shot 8-83-7.

B. Loading Records

The loading records are shown in Figure 7 in order of the shot sequence. Shots 8-83-2 and 8-83-3 are for the two aluminum panels. Shots 8-83-4 and 8-83-5 are for the two pine beam closures. Shot 8-83-6 is for the oak planks with sand bag protection. Shot 8-83-7 is the input for the oak beam closure. The increase in pressure after about 150 m is caused by the cold gas part of the shock wave loading the closure. All the other pressure-time records show a decay in pressure after the shock front, caused by the closures breaking. A rarefaction wave from the opened closure partially decays the expected flat topped input wave.

C. High Speed Photographs

The high speed camera was positioned to the south of the end of the shock tube. The camera's field of view covered from the end flange to about 2.4 m beyond the flange.

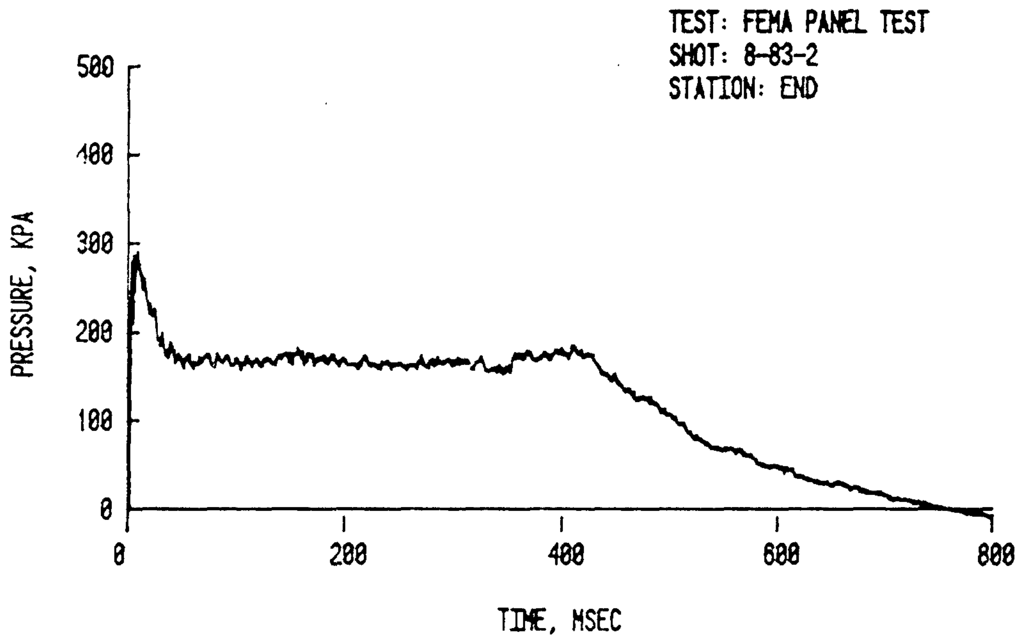
Films were obtained for Shots 8-83-2, 8-83-4, 8-83-5, and 8-83-6 with a framing rate of 500 PPS. No film is shown of Shot 8-83-7 since the closure did not blow out. Failure for the aluminum closure was shortly after impact. By about 14 ms (Figure 8) the closure was exiting the flange opening. Rotation accompanied the translation. The average translational velocity after 62 ms was about 45 m/sec.

Shots 8-83-4 and 8-83-5 (Figures 9 and 10) show the pine closures failed by breaking along a vertical centerline of the flange opening. Large sections of the beams rotated outward away from the shock tube axis.

 Text Continued on Page 35

TABLE 1. TEST CONDITIONS FOR CLOSURES

Shot No.	Type Closure	Loading Pressure kPa	Loading Pressure psi	Ambient Pressure kPa	Ambient Temperature °C	Opening Width cm	Opening Width in.	Damage to Closure
8-83-2	Al skins/I-Beams 7.62 cm (3 in.)	253	36.7	100.7	29.4	121.9	48	Broken out
8-83-3	Al Skins/I-Beams- 7.62 cm (3 in.)	247	35.8	100.8	6.7	121.9	48	Broken out
8-83-4	Pine Beams- 12.06 cm (4-3/4 in.) thick	351	50.9	101.8	8.9	121.9	48	Broken out
8-83-5	Pine Beams- 12.7 cm (5 in.) thick	347	50.3	102.0	16.1	121.9	48	Broken out
8-83-6	Oak Planks- 5.08 cm (2 in.) thick w/sand bags	344	49.9	101.8	16.7	121.9	48	Broken out
8-83-7	Oak Beams- 12.7 cm (5 in.) thick	342	49.6	102.7	27.8	121.9	48	1 beam cracked
8-83-8	Oak Beams- 7.62 cm (3 in.) thick	344	49.9	100.1	0.6	76.2	30	Broken out



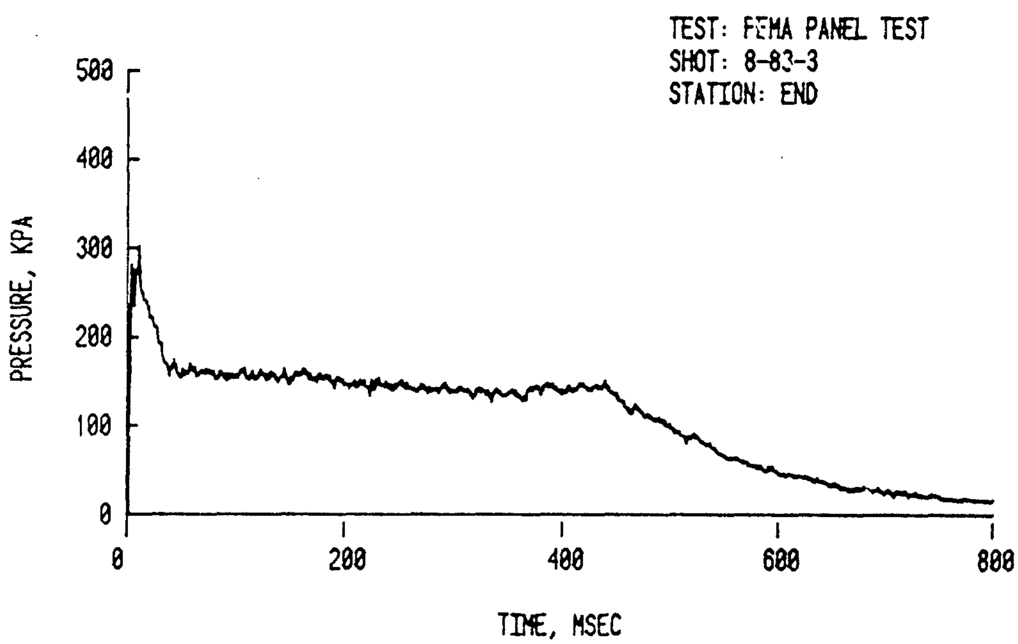
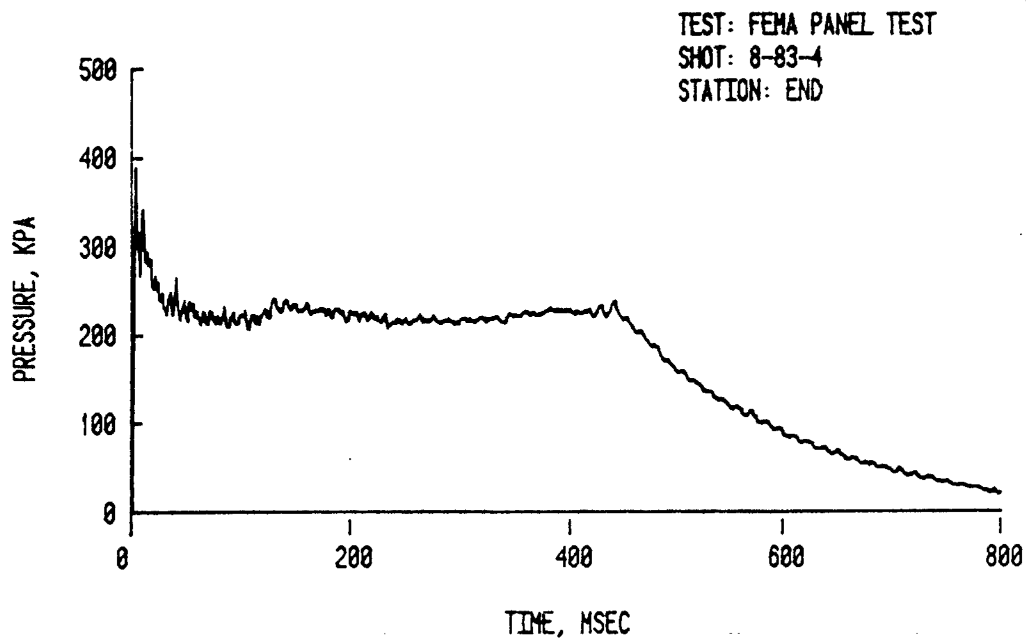


Figure 7. Input Loading - Time Records.



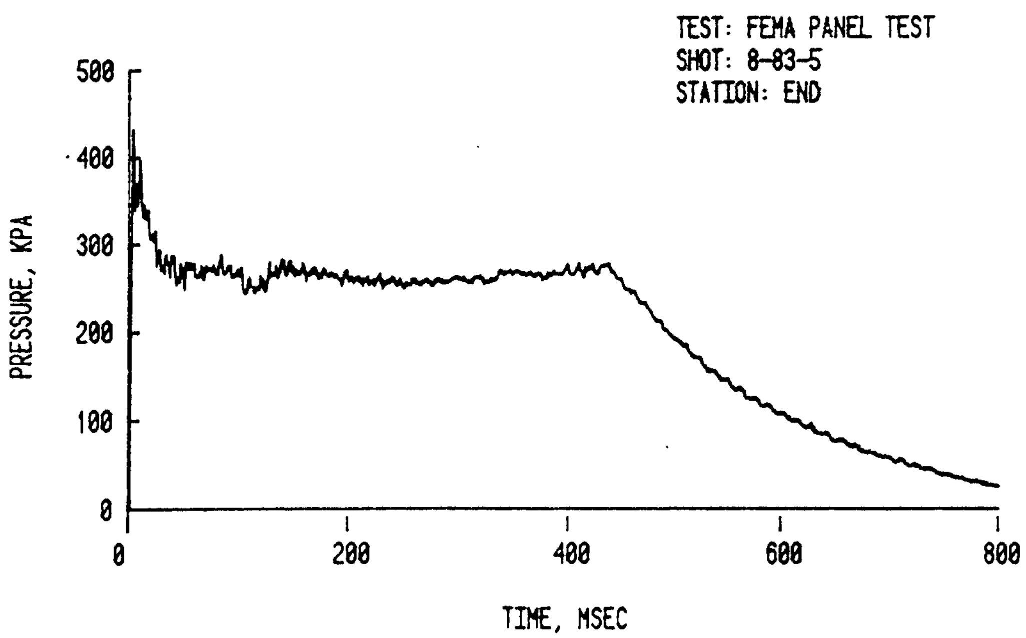
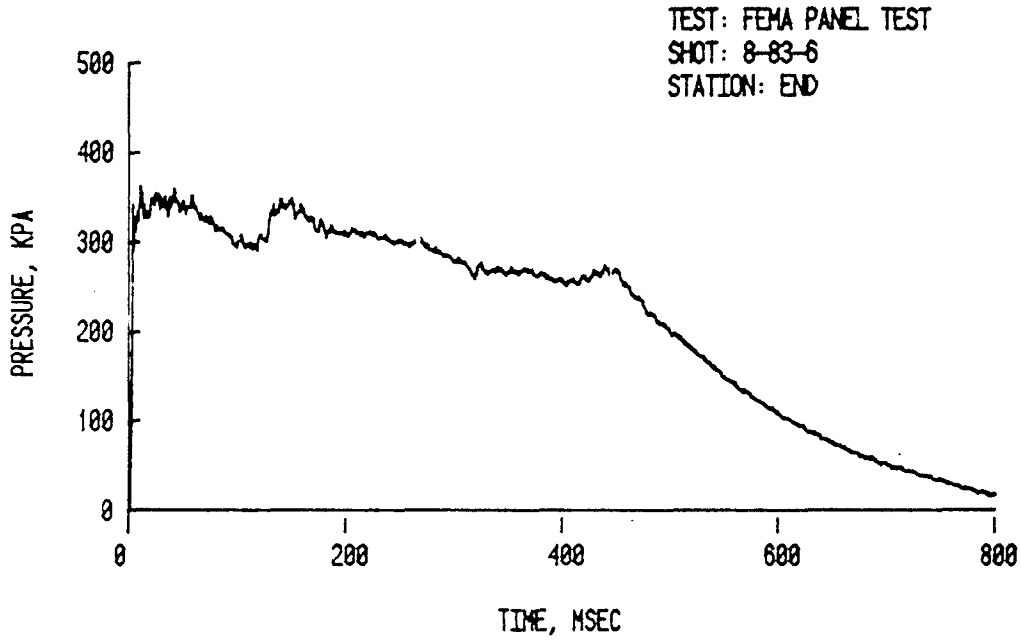


Figure 7 (Cont'd). Input Loading - Time Records.



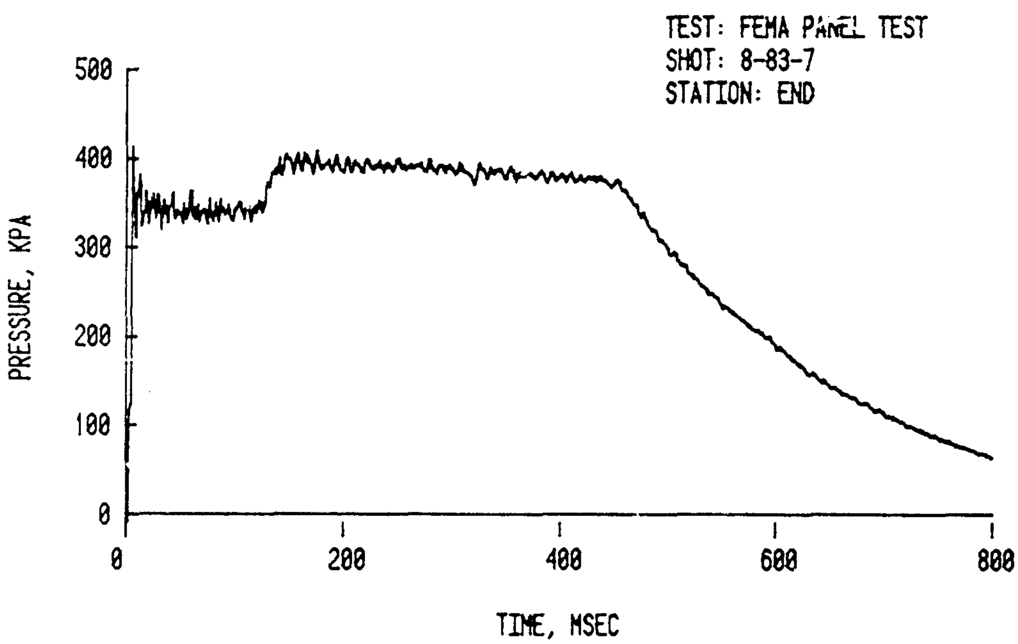


Figure 7 (Cont'd). Input Loading - Time Records.

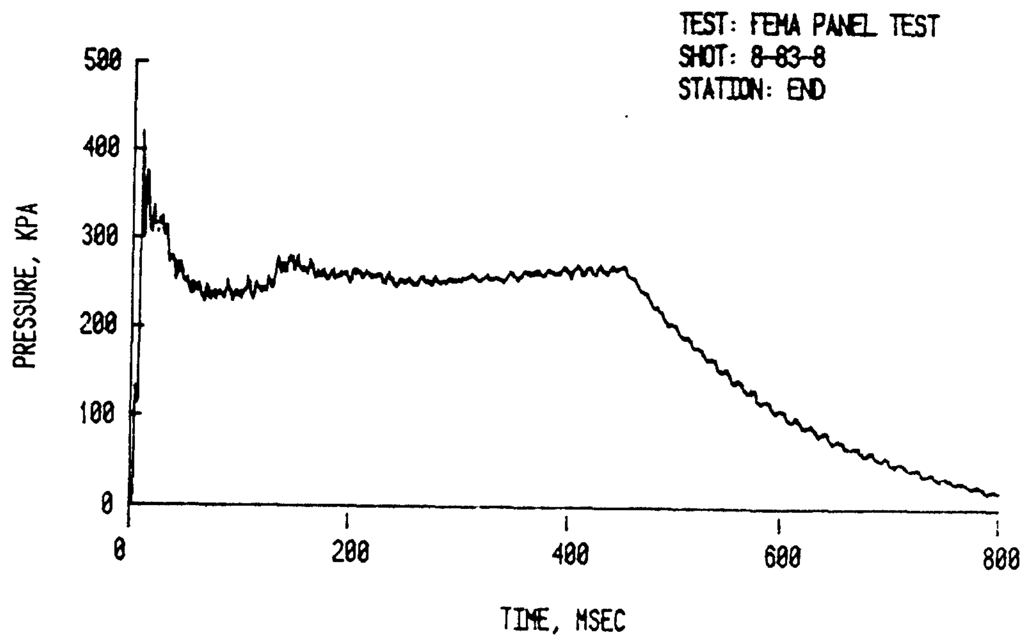
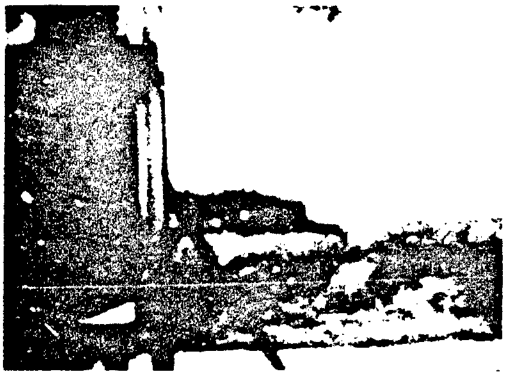


Figure 7 (Cont'd). Input Loading - Time Records.

Shot 8-83-2



0 ms

20 ms

14 ms

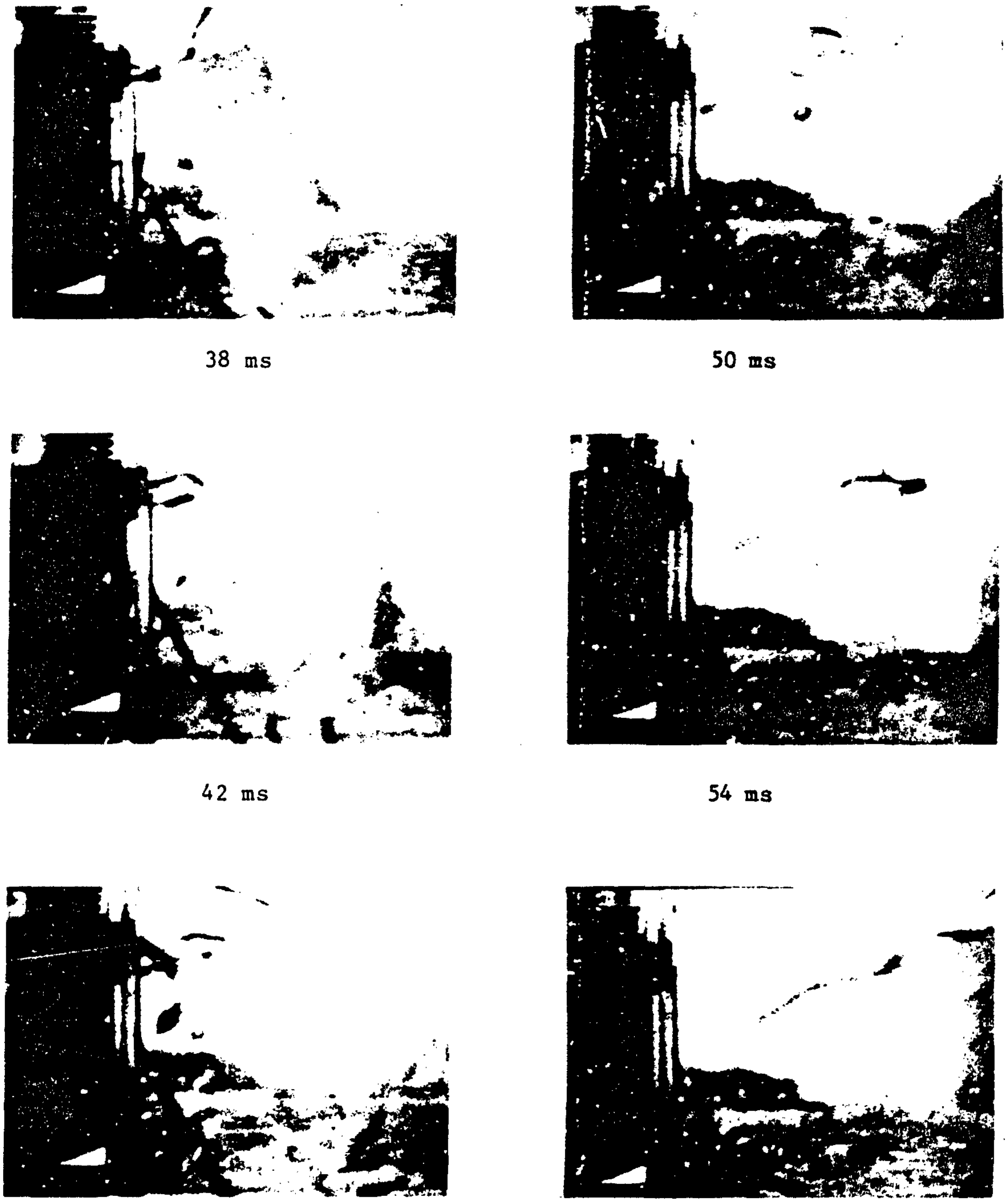
26 ms

18 ms

34 ms

Figure 8. Aluminum Skin/I-Beam Closure - 247 kPa (35.8 psi).

Shot 8-83-2



38 ms

50 ms

42 ms

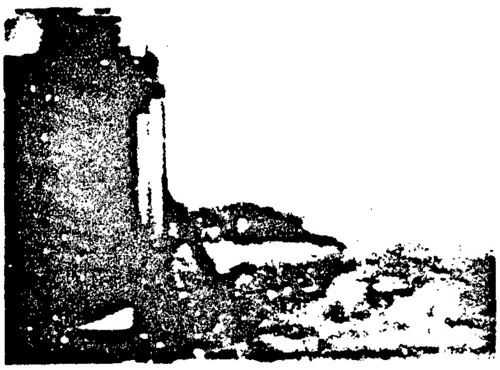
54 ms

46 ms

58 ms

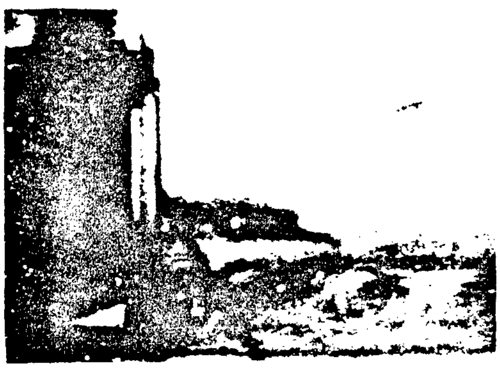
Figure 8 (Cont'd). Aluminum Skin/I-Beam Closure - 247 kPa (35.8 psi).

Shot 8-83-2

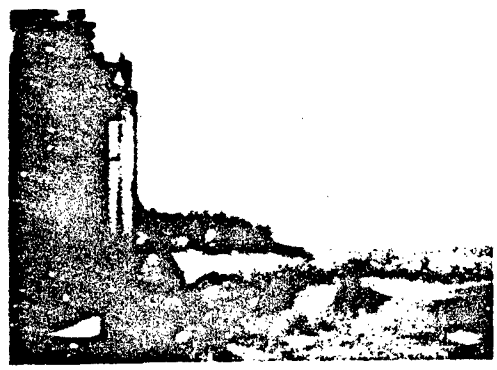


62 ms

70 ms



66 ms



74 ms

Figure 8 (Cont'd). Aluminum Skin/I-Beam Closure - 247 kPa (35.8 psi).

Shot 8-83-4

0 ms

36 ms

14 ms

46 ms

24 ms

56 ms

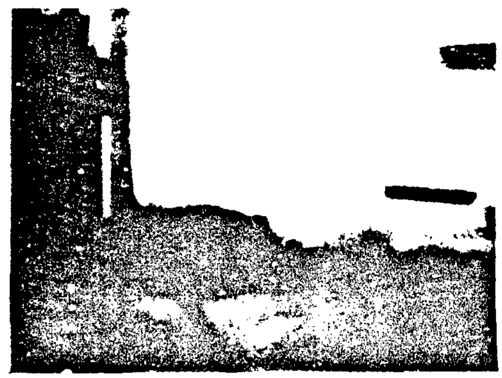
Figure 9. Pine Beam Closure - 351 kPa (50.9 psi).

Shot 8-83-4

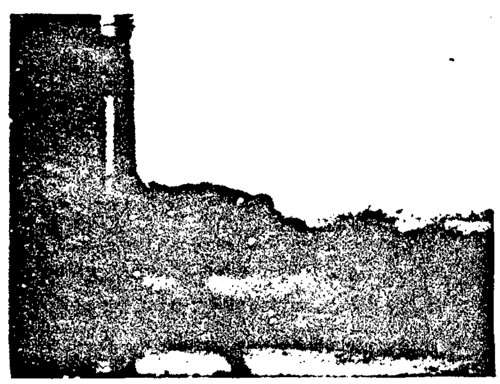
64 ms

74 ms

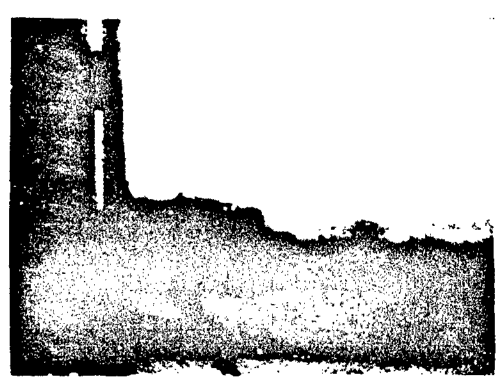
84 ms



94 ms



104 ms

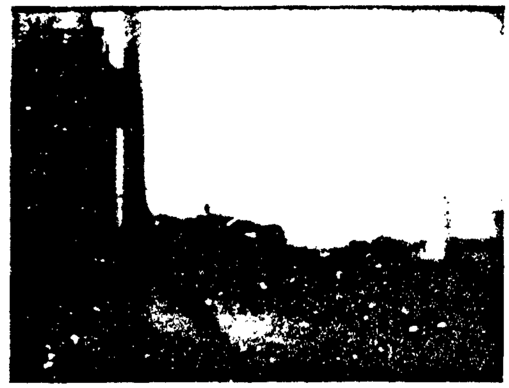


114 ms

Figure 9 (Cont'd). Pine Beam Closure - 351 kPa (50.9 psi).

Shot 8-83-4

124 ms



144 ms

134 ms

154 ms

Figure 9 (Cont'd). Pine Beam Closure - 351 kPa (50.9 psi).

Shot 8-83-5

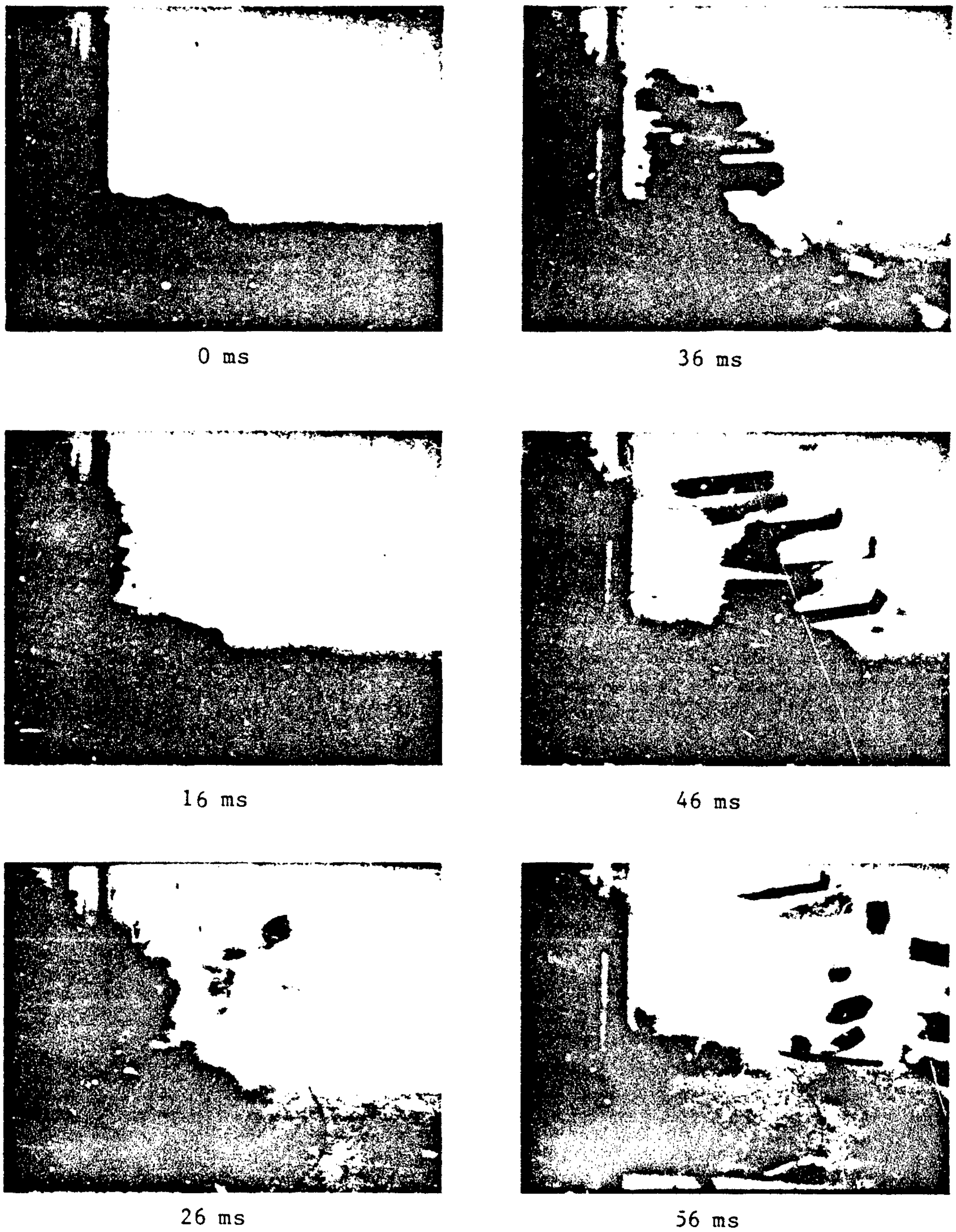


Figure 10. Pine Beam Closure - 347 kPa (50.3 psi).

Shot 8-83-5

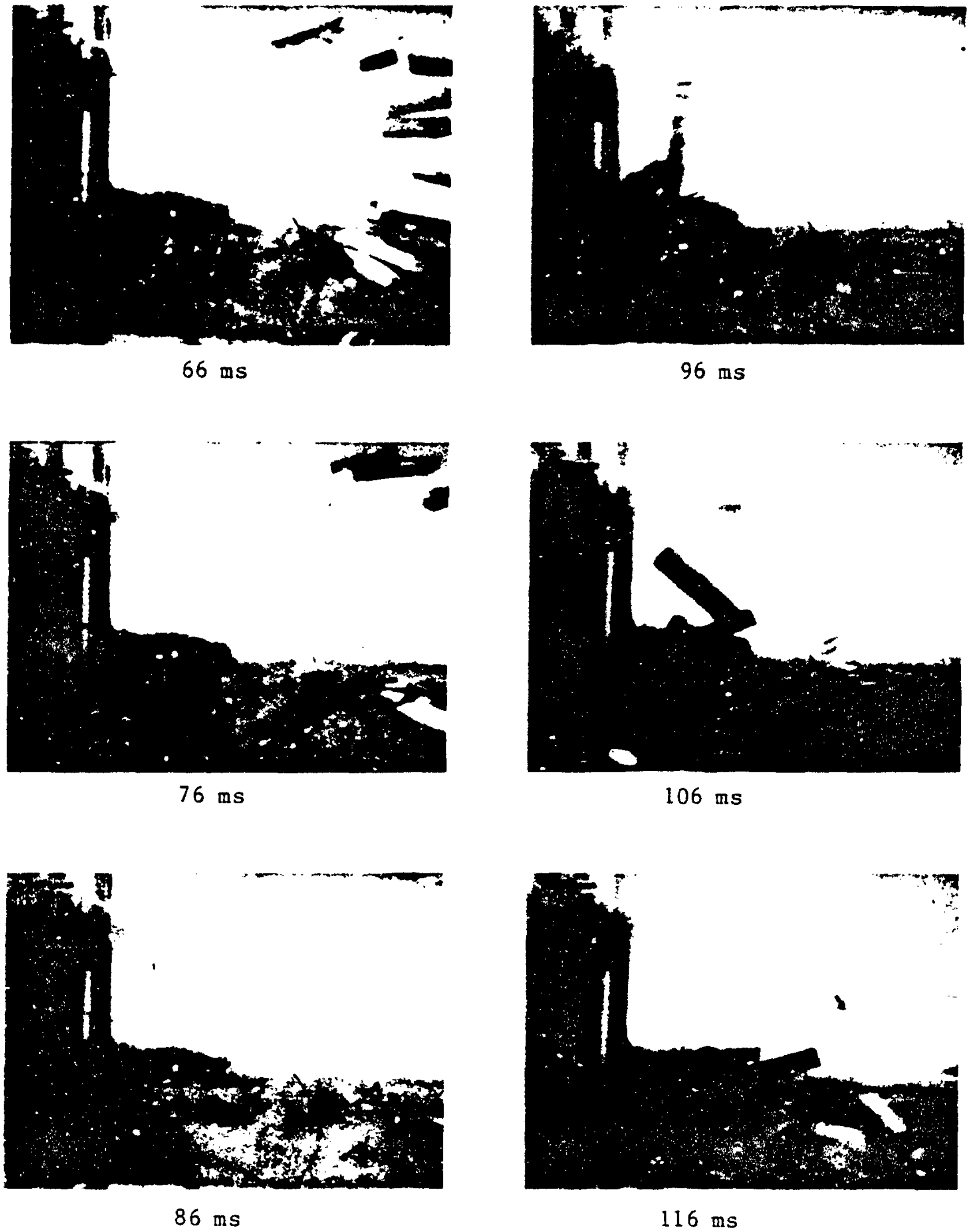
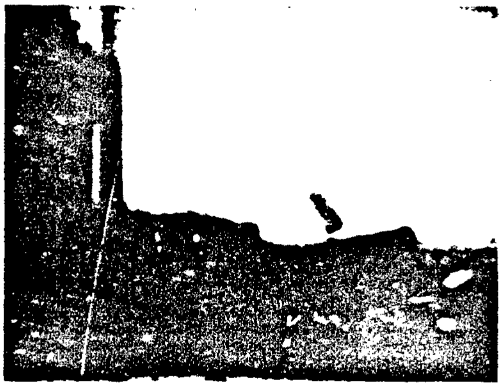


Figure 10 (Cont'd). Pine Beam Closure - 347 kPa (50.3 psi).

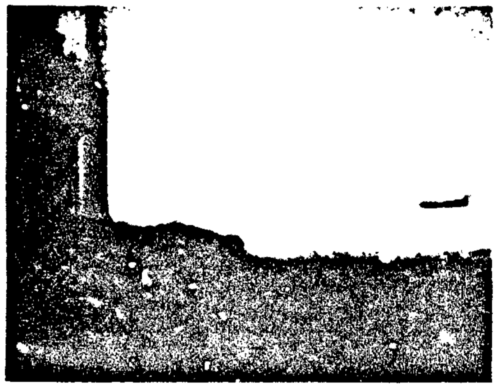
Shot 8-83-5



126 ms

136 ms

146 ms



156 ms

166 ms

Figure 10 (Cont´d). Pine Beam Closure - 347 kPa (50.3 psi).

Average velocities of about 40 m/s were observed after 64 ms.

Shot 8-83-6, with sand bags, is obscured with flying sand very quickly in Figure 11. The sand bags effectively delayed the breaking of the oak planks; very little debris exited before 70 ms. The pressure-time record for Shot 8-83-6, Figure 7 above points this delay out also.

The next section shows a series of still photographs of the closures, illustrating in more detail the failure modes.

D. Failure Modes

Figure 12 illustrates the mounted closure in the upper picture and portions of the closure in the lower picture after exposure to the shock wave. Almost without exception, the plug welds broke from the I-beams without leaving the skins. Neither of the two aluminum closures tested were satisfactory for the key worker blast pressure levels.

Figure 13 shows results from the tests of the pine beam closures. The failure was primarily about the flange opening's vertical centerline. The scattered broken beams were gathered from over the test area for this posed picture.

Figure 14 shows a slight break in the center beam after exposure to the blast loading. Notice the almost complete lack of knots as compared to the pine closure. This closure successfully contained the blast wave; no blast pressure escaped. These beams were judged to be No. 1 grade since there were almost no knots.

Figure 15 shows the results of the oak plank/sand bag closure. As noted from the high speed photographs, failure did not occur until after perhaps 50 ms. This closure was just on the borderline of being satisfactory. One beam did remain in the test fixture but all sand bags were blown out. Figure 15-C shows the shredded state of the sand bags collected after the shot.

Finally, Figure 16, shows the method of mounting the oak beam closure over a 76.2 cm (30 in.) opening. The mounting braces and the closure were completely removed during the blast wave exposure. It is felt that the closure did contain the blast for a short time (perhaps 30 ms) until the steel side mounts were torn loose. The closure might have withstood the blast loading if the side mounts had remained intact. The plank/sand bag closure is considered to be marginal at the pressure level tested.

IV. ANALYSIS

The analysis follows the upgrading procedures found in Reference 5. See Table 2 for material properties.

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Shot 8-83-6

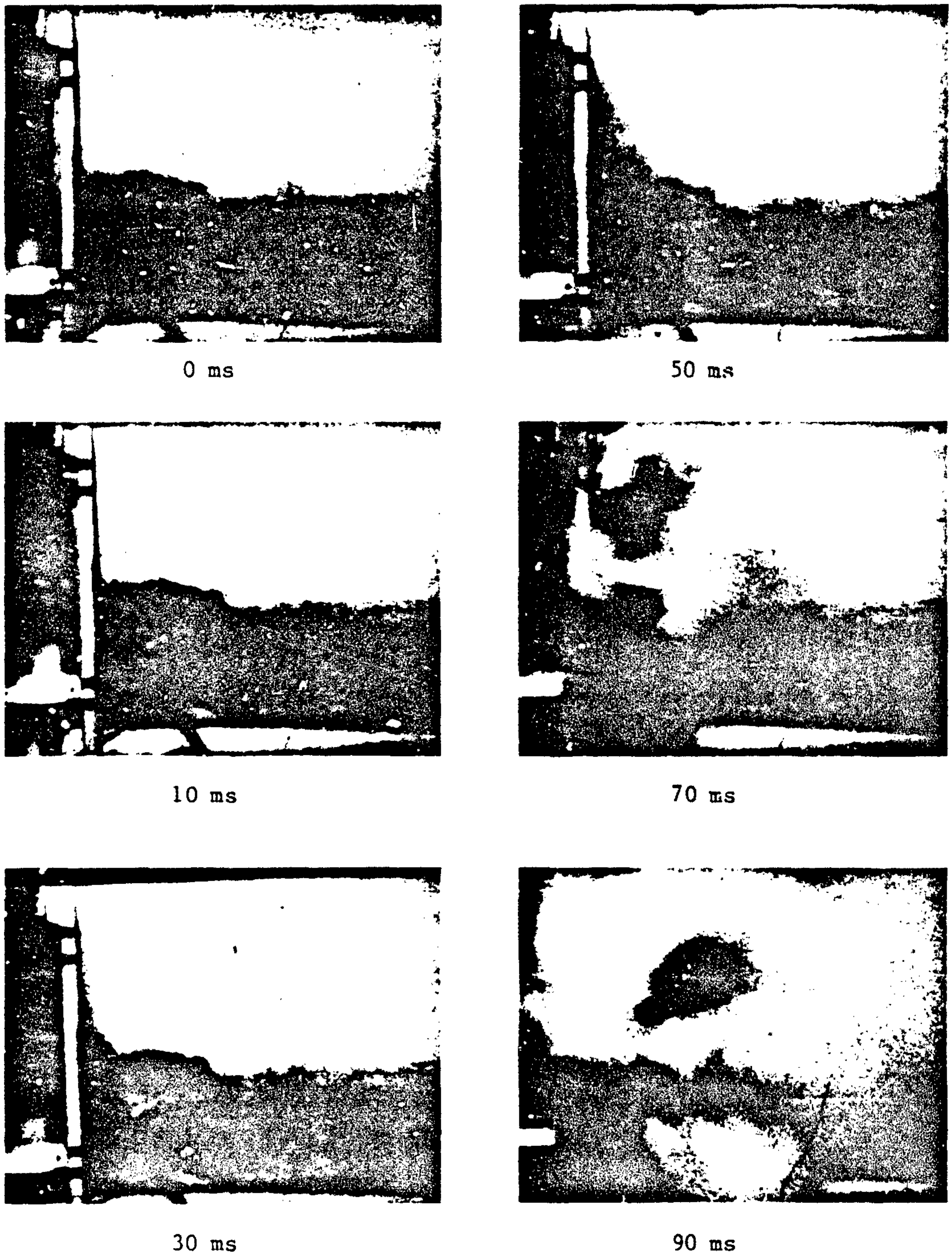


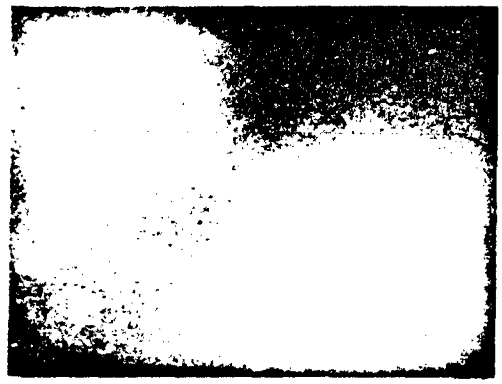
Figure 11. Sand Bag/Plank Closure - 344 kPa (49.9 psi).

Shot 8-83-6

110 ms

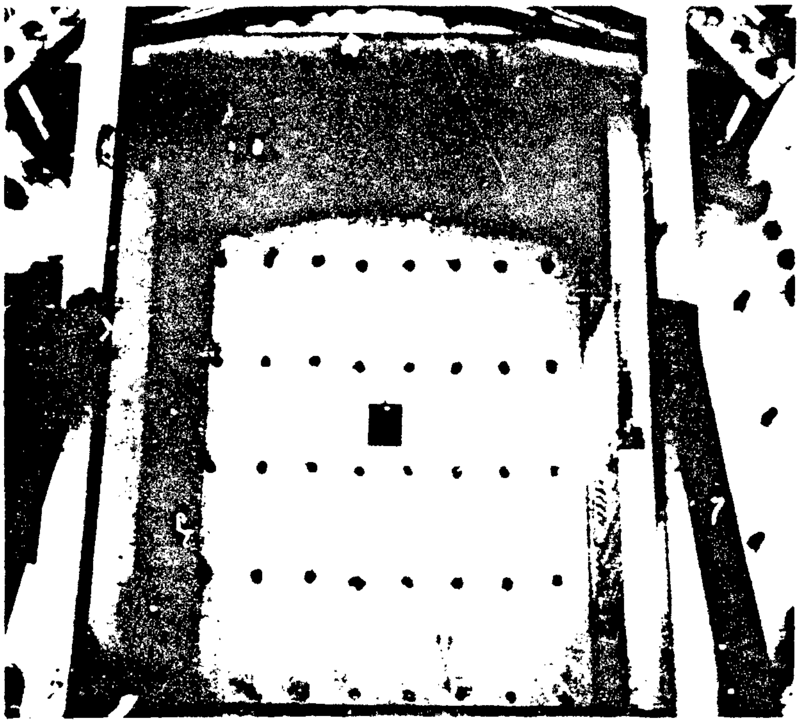
150 ms

130 ms

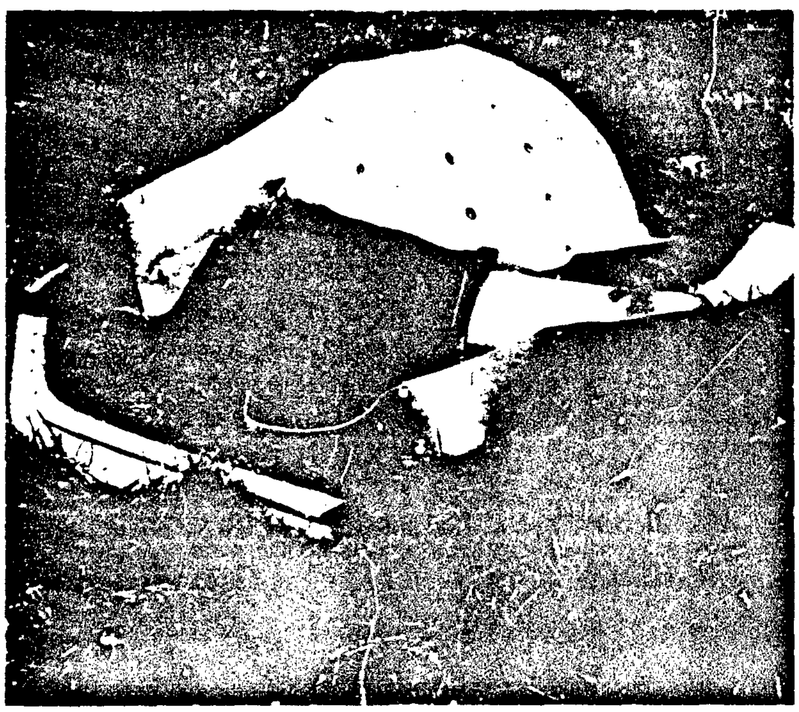


170 ms

Figure 11 (Cont'd). Sand Bag/Plank Closure - 344 kPa (49.9 psi).



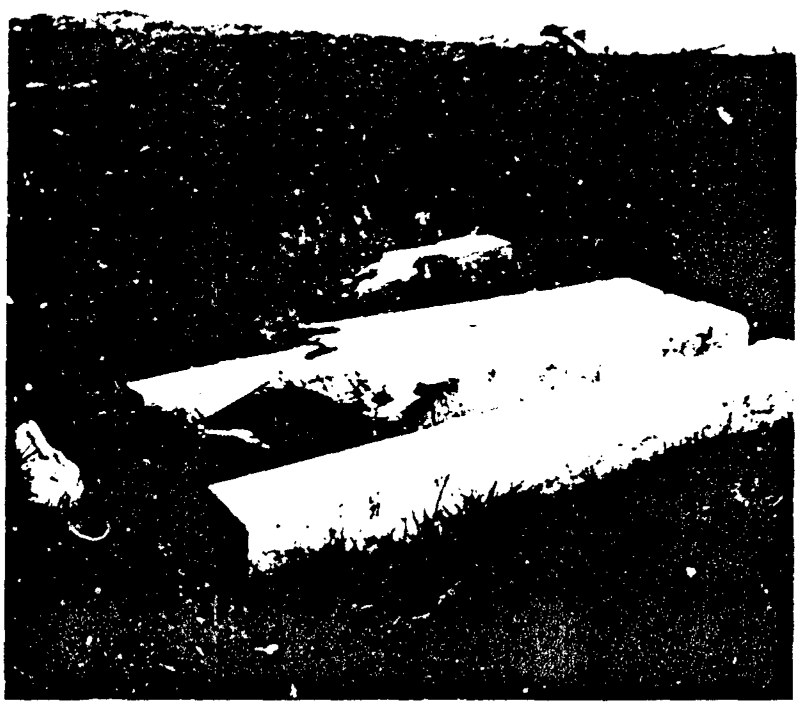
A. Pre-Shot 8-83-3



B. Post-Shot 8-83-3

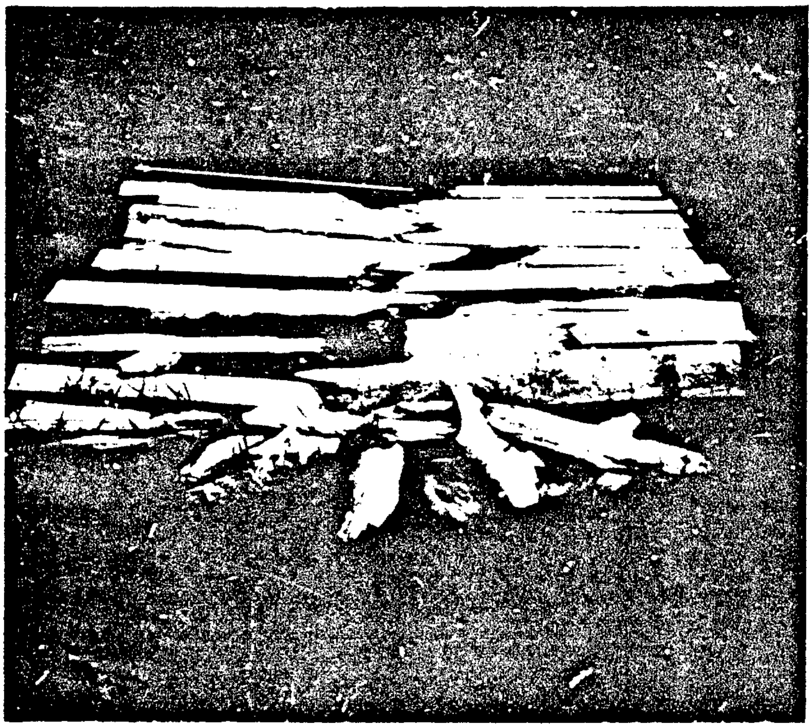
Figure 12. Failure Mode for Aluminum Closure - 247 kPa (35.8 psi).

A. Pre-Shot 8-83-5



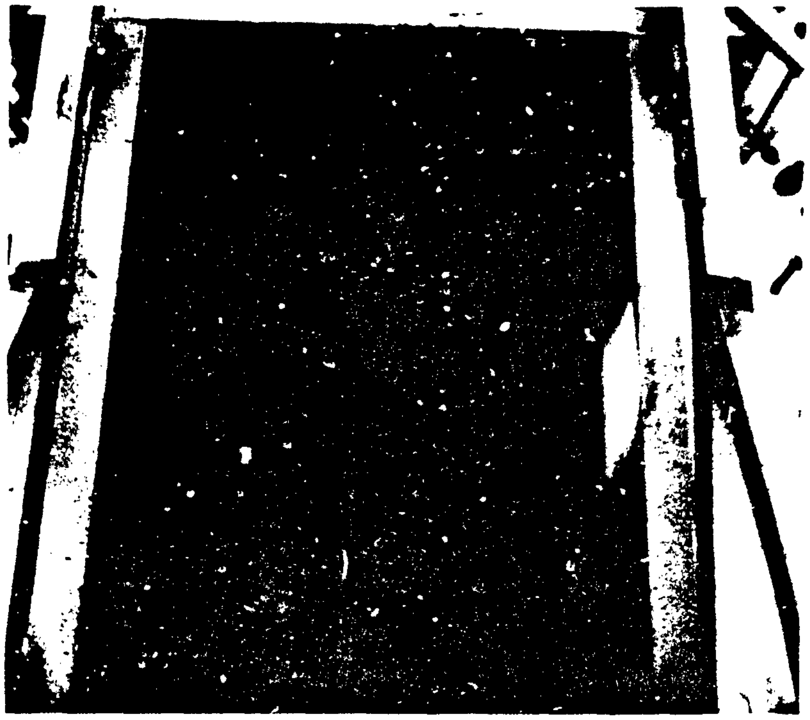
B. Post-Shot 8-83-5

Figure 13. Failure Mode for Pine Beam Closure - 347 kPa (50.3 psi).

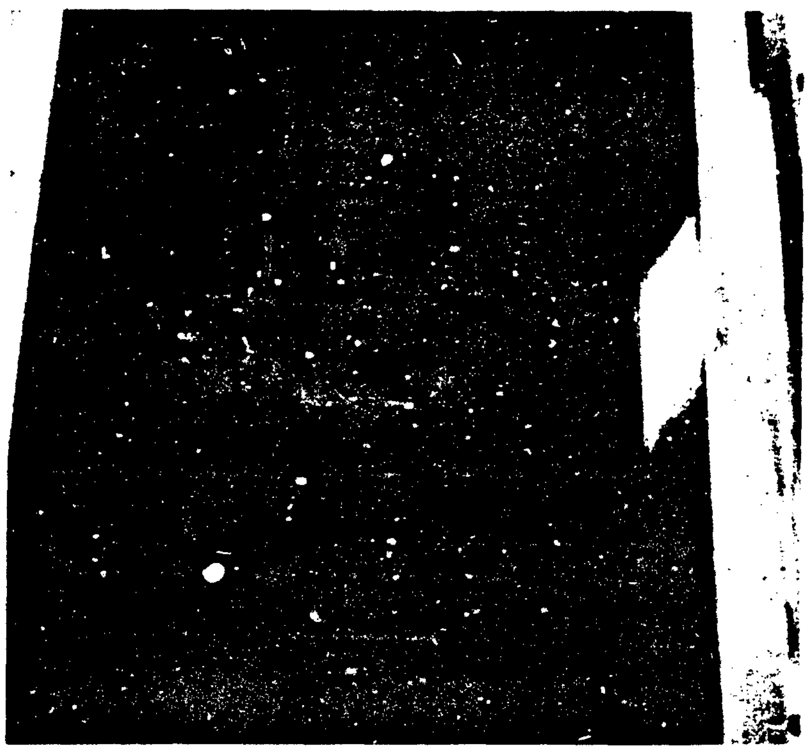


C. Post-Shot 8-83-4

Figure 13 (Cont'd). Failure Mode for Pine Beam Closure - 347 kPa (50.3 psi).

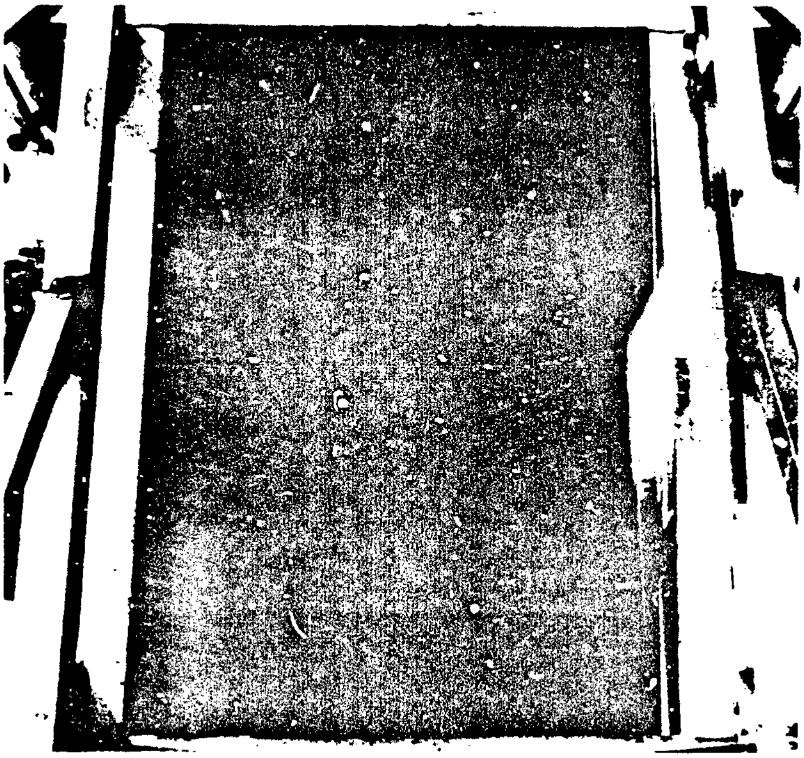


A. Pre-Shot 8-83-7

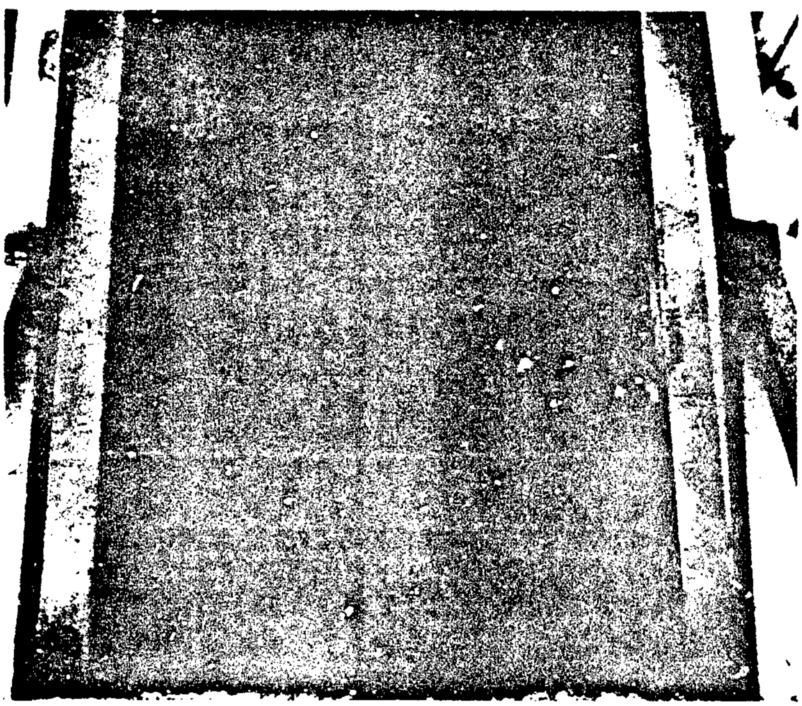


B. Post-Shot 8-83-7

Figure 14. Oak Beam Closure - 342 kPa (49.6 psi).

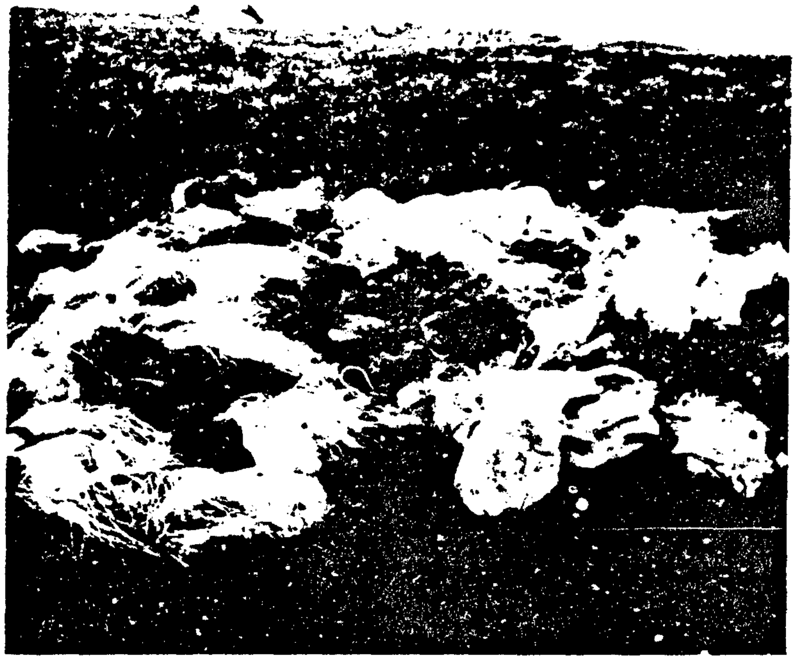


A. Pre-Shot 8-83-6



B. Post-Shot 8-83-6

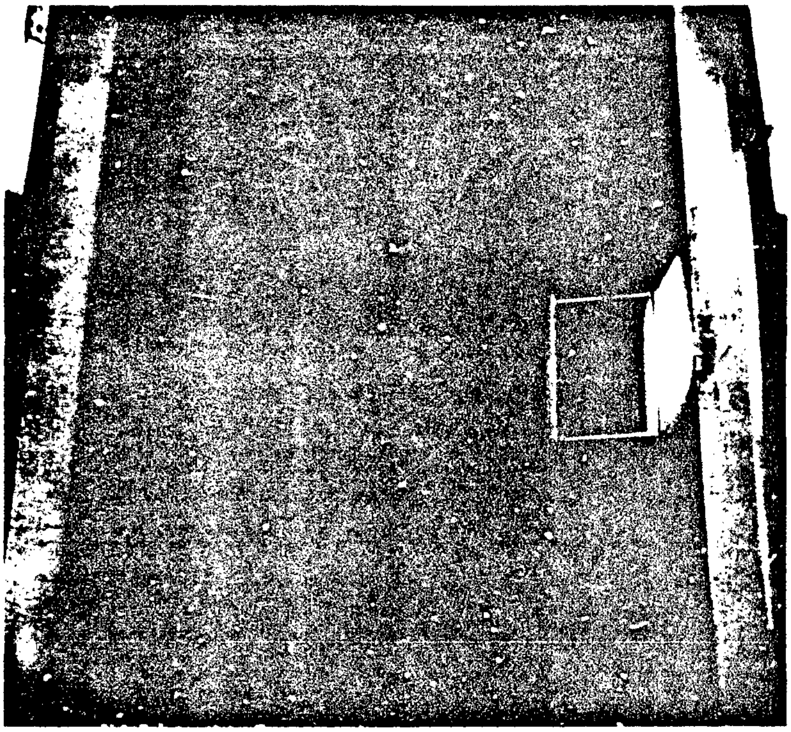
Figure 15. Oak Plank/Sand Bag - 344 kPa (49.9 psi).



C. Sand Bags from Shot 8-83-6

D. Oak Planks from Shot 8-83-6

Figure 15 (Cont'd). Oak Plank/Sand Bag - 344 kPa (49.9 psi).



Pre-Shot 8-83-8

Figure 16. Oak Beam Closure, 76.2 cm (30 in.).

TABLE 2. MATERIAL PROPERTIES OF THE CLOSURES

Material	Grade	F_b kPa	F_b psi	F_v kPa	F_v psi	E kPa	E psi	G kPa	G psi	Yield Strength kPa	Yield Strength psi	Shear Strength kPa	Shear Strength psi
Aluminum Sheet 0.318 cm (1/8 in.)	6061-T4[a]	-	-	-	-	68.95×10^6	10×10^6	26.2×10^6	3.8×10^6	144,799	21,000	165,474	24,000
Aluminum I-Beam 7.62 cm (3 in.)	6061-T6	-	-	-	-	68.95×10^6	10×10^6	26.2×10^6	3.8×10^6	275,790	40,000	206,842	30,000
Pine Beam 12.7 cm (5 in.)	No. 2[b]	5,860	850	482.6	70	8.96×10^6	1.3×10^6	-	-	-	-	-	-
Oak Beam 12.7 cm (5 in.)	No. 1[c]	8,274	1200	586.0	85	12.41×10^6	1.8×10^6	-	-	-	-	-	-

[a]See References 8 and 9.

[b]See Reference 10.

[c]The oak beams were ungraded, but were judged visually to be No. 1 grade timber.

A. Aluminum Skin/I-Beam Closure

Horizontal shear was found to be the weakest failure mode of plywood skin/wood stringer panels. A check of bending deflection, and horizontal shear showed it to be true, also for the aluminum skin/I-beam closure. The allowable total load-horizontal shear was calculated from the following equation:

$$P_v = (2\ F_v t/(\ell \ell' Q_v))(EI_g/E_{I\text{-beam}}), \tag{1}$$

where
P_v = allowable load-horizontal shear (kPa),
F_v = allowable stress in I-beam weld-shear (kPa),
t = average weld width distributed along all the I-beams (cm),
EI_g = stiffness factor from Figure 17 (kPa-cm^4),
$E_{I\text{-beam}}$ = modulus of elasticity (kPa),
ℓ = clear span of panel, direction of I-beams (cm),
ℓ' = width of panel (cm), and
$Q_v = Q_{I\text{-beam}} + Q_{skin}\ (E_{skin}/E_{I\text{-beam}})$.

Property values were taken from References 8 and 9. The terms of Q_v are:

$Q_{I\text{-beam}}$ = cross section of all I-beams above or below neutral axis (N.A.) multiplied by its centroidal distance from N.A. (cm^3).

$Q_{skin} = A_{11}$ for skin multiplied by moment arm (cm^3), and

$E's$ = moduli of elasticity (kPa).

For values of F_v = 165,474 kPa, t = 0.61 cm, EI_g = 15.86 x 10^{10} kPa - cm^4, $E_{I\text{-beam}}$ = 68.95 x 10^6 kPa, ℓ = 121.9 cm, ℓ' = 167.0 cm, Q_v = 304.5 cm^3, and E_{skin} = 68.95 x 10^6 kPa, the allowable horizontal stress, P_v=74.76 kPa (10.84 psi).

The dynamic load required to cause ultimate failure is:

$$P_{dm} = 4\ P_v\ (1 - 1/2\mu), \tag{2}$$

where the ductility factor, μ, is taken as 5 for aluminum,

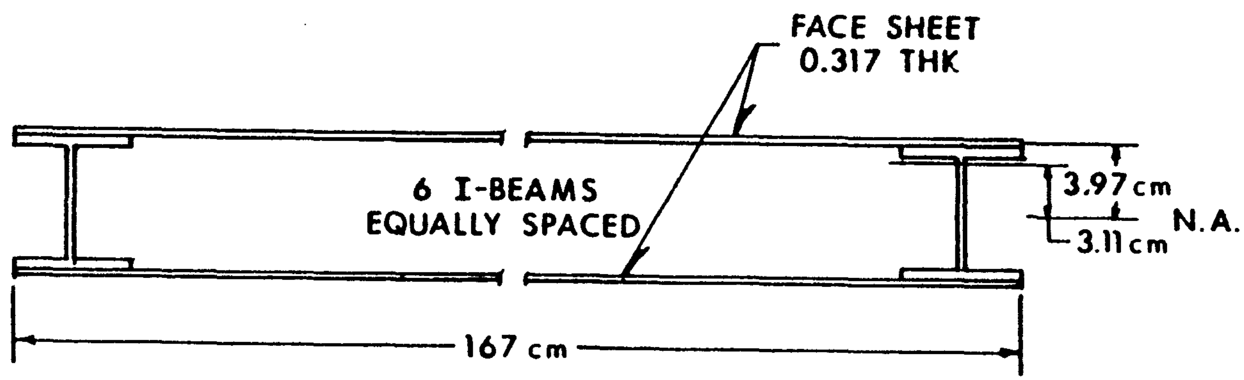
$$P_{dm} = 3.6\ P_v. \tag{3}$$

The predicted load to cause ultimate failure of the aluminum skin/I-beam closure is 269.1 kPa (39.02 psi).

---

[8] *Handbook, Atlantic Copper and Brass Co., 317 President St., Baltimore, MD 21202, May 1977.*

[9] *Theodore Baumeister, Editor, Marks' Mechanical Engineers' Handbook, Sixth Edition, McGraw-Hill Book Company, New York, NY, 1958.*



	E kPa	I cm^4	A_{11} cm^2	d_1 cm	d_1^2 cm^2	$A_{11} d_1^2$ cm^4	$I + A_{11} d_1^2$ cm^4	$E(I + A_{11} d_1^2)$ kPa - cm^4
FACE SHEET	68.95×10^6	0.44	53.01	3.97	15.74	834.62	835.06	5.75×10^{10} (× 2)
I-BEAM	68.95×10^6	632.46	60.38	0.00	0.00	0.00	632.46	4.36×10^{10}

$EI_g = 15.86 \times 10^{10}$ kPa - cm^4

Figure 17. Calculation of Stiffness Factor for Aluminum Skin/I-Beam Closure.

B. Wood Beam Closure

Primary modes of failure, Reference 5, are in bending and horizontal shear. The relation for bending resistance is given as Equation 4:

$$q_b = 0.5\ F_b\ (d/\ell)^2/(3C), \tag{4}$$

where F_b = extreme fiber stress in bending (kPa),
d = thickness (depth) of beam (cm),
ℓ = clear span (cm), and
C = 1/8 for simply supported beams.

For values of F_b = 5,860 and 8,274 kPa,[10] d = 12.7 cm, ℓ = 121.9 cm, and C = 1/8, the allowable stress in bending q_b is 84.8 kPa (12.3 psi) and 119.7 kPa (17.4 psi).

The dynamic load to cause ultimate failure in bending is:

$$P_{dm} = 4\ q_b\ (1 - 1/2\mu), \tag{5}$$

where μ is taken as 3 for wood.

$$P_{dm} = 3.333\ q_b. \tag{6}$$

The predicted loads to cause ultimate failure in bending are 282.6 kPa (41.0 psi) for the No. 2 pine and 399.0 kPa (58.0 psi) for the No. 1 oak.

The horizontal shear resistance is found from Equation 7:

$$q_v = 2F_v\ d\ (3c'\ (\ell - 2d)), \tag{7}$$

where F_v = horizontal shear stress (kPa),
d = thickness (depth) of beam (cm),
c' = 1/2 for simply supported beams, and
ℓ = clear span (cm).

For values of F_v = 482.6 (for pine) and 586 kPa (for oak), d = 12.7 cm, c' = 1/2, and ℓ of 121.9 the allowable stress in horizontal shear, q_v, is 84.6 kPa (12.3 psi) for the No. 2 pine and 102.8 kPa (14.9 psi) for the No. 1 oak.

The dynamic load to cause ultimate failure in horizontal shear is calculated from Equation 6 with q_v used instead of q_b. The two values (for pine and oak) are 282.0 kPa (40.9 psi) and 342.6 kPa (49.7 psi).

Comparing the two modes of failure, bending and shear, the shear is somewhat weaker and should be used for predictions of the ultimate failure to be expected for the beam closures.

---

[10] *"Design Values for Wood Construction - A Supplement to the 1977 Edition of National Design Specification for Wood Construction," National Forest Products Association, 1619 Mass Ave., NW Wash., DC 20036, April 1980.*

Table 3 compares these predicted values of failure with the experimental results. No failure predictions were attempted for the sand bag/ plank closure.

It would have been more desirable to have chosen a greater variety of materials to be exposed to the blast wave loading. However, funding limitations would not permit this. Figure 18 shows the prediction curves from Reference 6 (for 276 kPa) converted to metric scale and upgraded to key worker area pressure as requested by the FEMA project office.

As noted previously in the results section, only one shot was fired with the sand bags in place. The closure did fail but only after a relatively long time. The curve for "closure - with sand bags" can at best be considered marginal at the test level of 345 kPa.

The closures, with no sand bags as noted, did survive with minimal damage at the stated level. There would however have been almost no safety factor remaining since one timber member was cracked during the shots. It is felt, however, that both curves of Figure 18 would have been accurate for the level of 276 kPa as originally presented in Reference 6. The results of these tests indicate the curves should not be upgraded to the higher level of input blast pressure.

V. SUMMARY AND CONCLUSIONS

The present work is a part of a research program sponsored by the Federal Emergency Management Agency (FEMA) to upgrade existing shelters for key worker areas. FEMA has sponsored the present research program at the Ballistic Research Laboratory (BRL) to determine the functional relationship between a particular thickness of closure material and the opening size to be covered. It was the desire of the FEMA project office to upgrade the anticipated pressure level for an existing set of closure material curves as given in Reference 6.

BRL designed and tested a set of closures to determine if the closure material/closure opening curves might be upgraded to the higher pressure level. Aluminum skin/I-beam and wood beam closures were exposed in the BRL 2.44 m shock tube at the increased pressure level of 344 kPa (49.9 psi). All closures tested failed completely except for the single oak beam closure without sand bags.

It is felt by the author that only near-perfect No. 1 and better wood timbers could be used for closures at the upgraded pressure level. The welds joining the aluminum skin/I-beam closures failed also at this level.

It is recommended that the particular materials versus opening size curves not be upgraded to a higher pressure level. No margin of safety is believed to exist at the higher level tested. Protection at this pressure level (344 kPa) could not be expected with most available lower grade materials. Revised curves should be published if the higher pressure level is desired by the FEMA project office.

TABLE 3. VALUES FOR ULTIMATE FAILURE

Type Closure	Allowable Static Load		Ultimate Failure Predicted		Experiment		Ratio Allowable Load
	kpa	psi	kpa	psi	kpa	psi	
Aluminum Skins/ I-Beams 7.62 cm (3 in.)	74.8	10.8	269.1	39.0	<247	35.8	-
Pine Beams 12.7 cm (5 in.)	84.6	12.3	282.0	40.9	<347	50.3	-
Oak Beams 12.7 cm (5 in.)	102.8	14.9	342.6	49.7	344	49.9	3.3
2x's Placed* Flat-3.81 cm (1.5 in.) thick	82.7	12.0	276	40.0	420	60.9	5.1

*Taken from Reference 2.

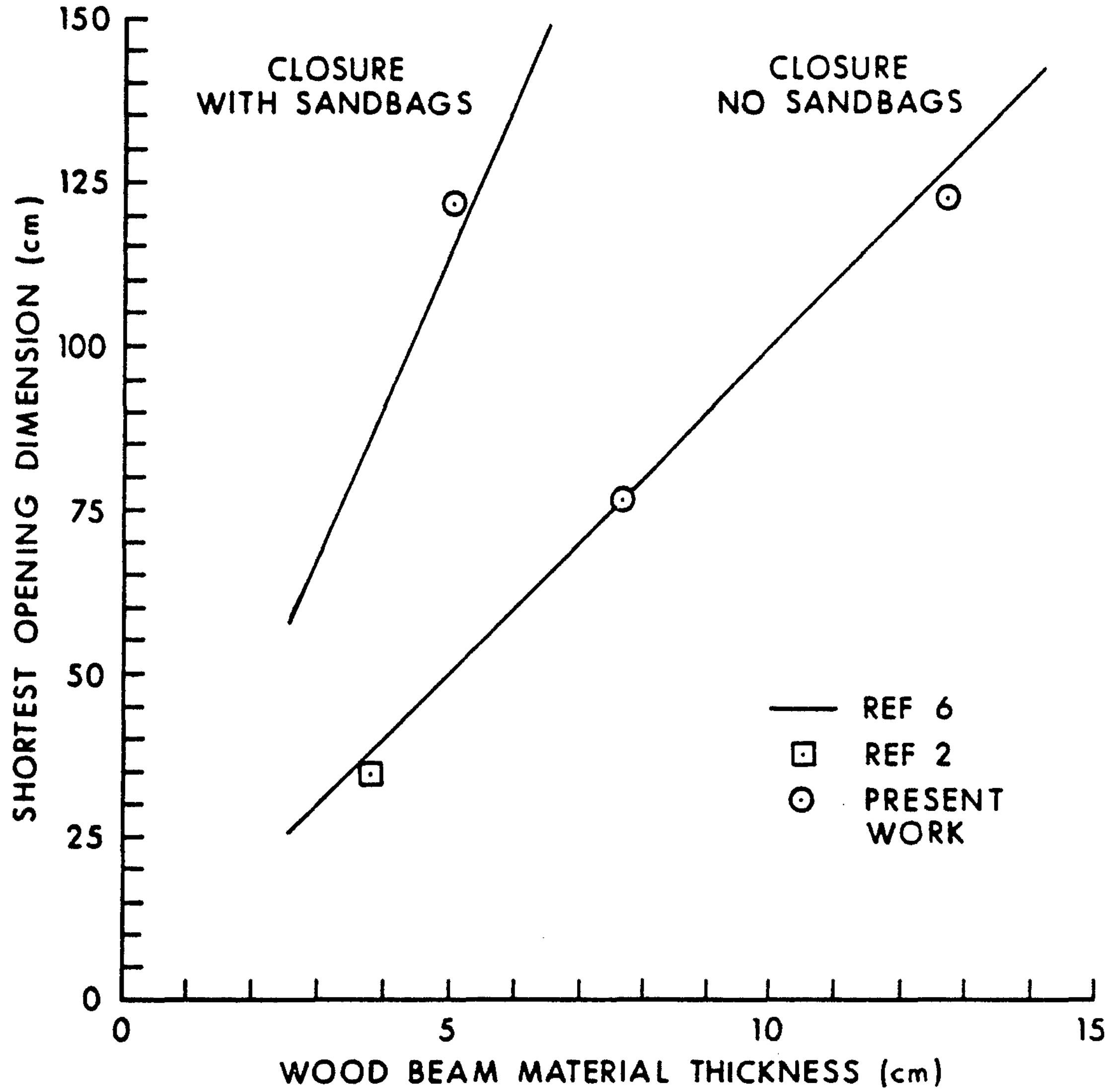


Figure 18. Material Thickness Required to Close Various Openings at the 345 kPa Ground Range.

ACKNOWLEDGEMENTS

The author wishes to thank Messrs. Kenneth Holbrook, James Bernhardt, and Sterling Dunbar for the careful experimental work performed at the BRL Shock Tube Facility.

REFERENCES

1. G.A. Coulter, "Debris Hazard from Blast Loaded Plywood Sheet Closures," Memorandum Report ARBRL-MR-02917, Ballistic Research Laboratory, March 1979 (AD A071460).

2. G.A. Coulter, "Blast Loading of Construction Materials and Closure Designs," Memorandum Report ARBRL-MR-02947, Ballistic Research Laboratory, August 1979 (AD A077116).

3. G.A. Coulter, "Blast Loading of Wall Panels and Commercial Closures," Memorandum Report ARBRL-MR-03154, Ballistic Research Laboratory, February 1982 (AD B063574L).

4. G.A. Coulter, "Blast Loading of Closures for Use on Shelters," Memorandum Report ARBRL-MR-03279, Ballistic Research laboratory, June 1983 (AD A130028).

5. H.L. Murphy, "Upgrading Basements for Combined Nuclear Effects: Predesigned Expedient Options II," SRI Project 6876 Technical Report, July 1980.

6. "Industrial Protection Manual, Booklet 10," SSI Report No. 8011, Scientific Service, Inc., June 1981 (AD A102631).

7. B.P. Bertrand, "BRL Dual Shock Tube Facility," Ballistic Research Laboratory Memorandum Report 2001, August 1969 (AD 693264).

8. Handbook, Atlantic Copper and Brass Co., 317 President St., Baltimore, MD 21202, May 1977.

9. Theodore Baumeister, Editor, Marks' Mechanical Engineers' Handbook, Sixth Edition, McGraw-Hill Book Company, New York, NY, 1958.

10. "Design Values for Wood Construction - A Supplement to the 1977 Edition of National Design Specification for Wood Construction, "National Forest Products Association, 1619 Mass Ave., NW Wash., DC 20036, April 1980.

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